Plate Tectonics

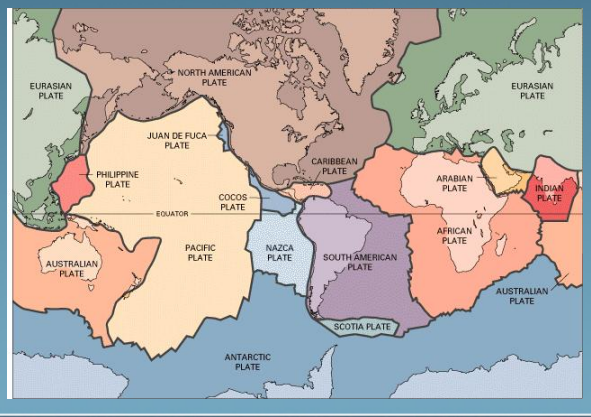
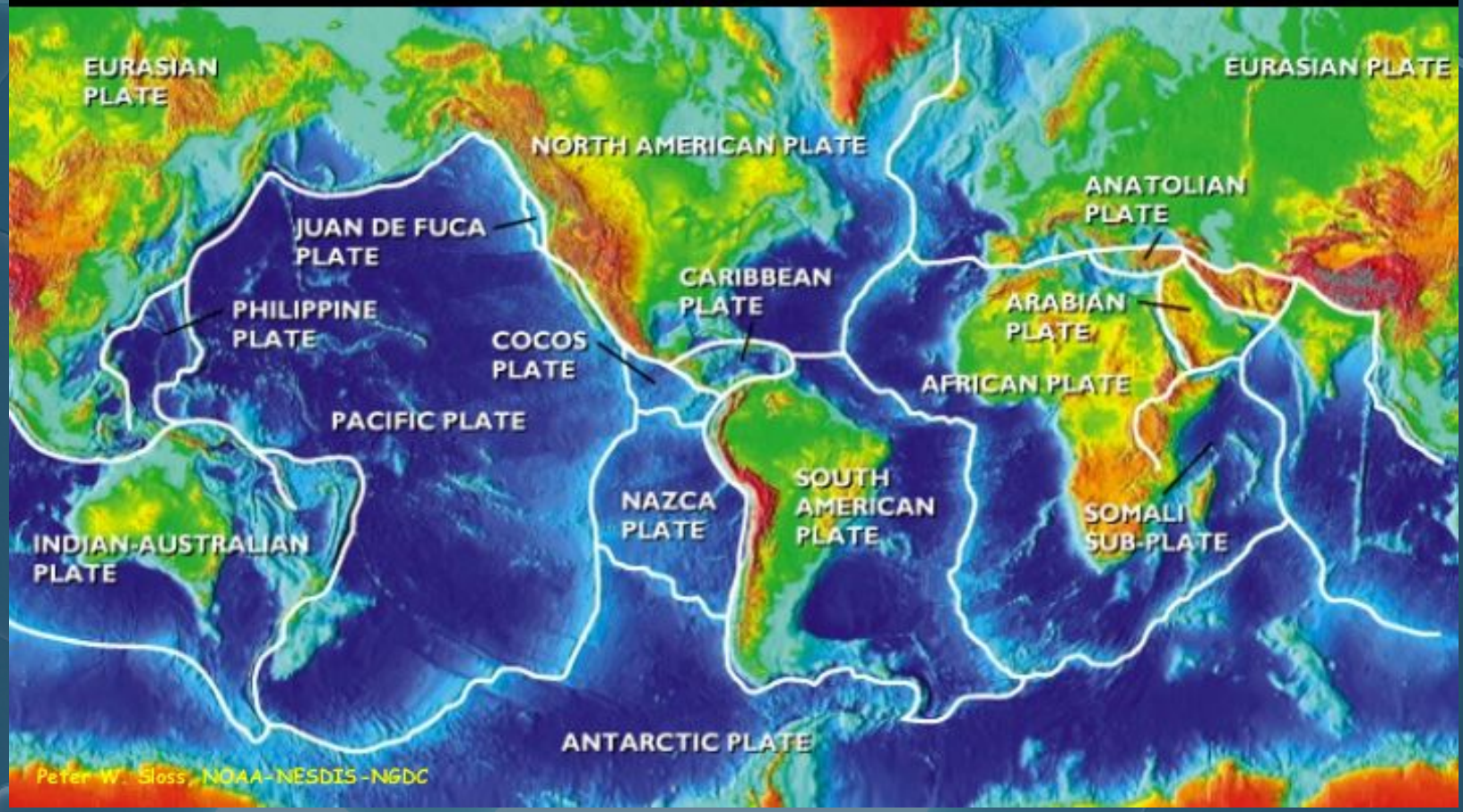


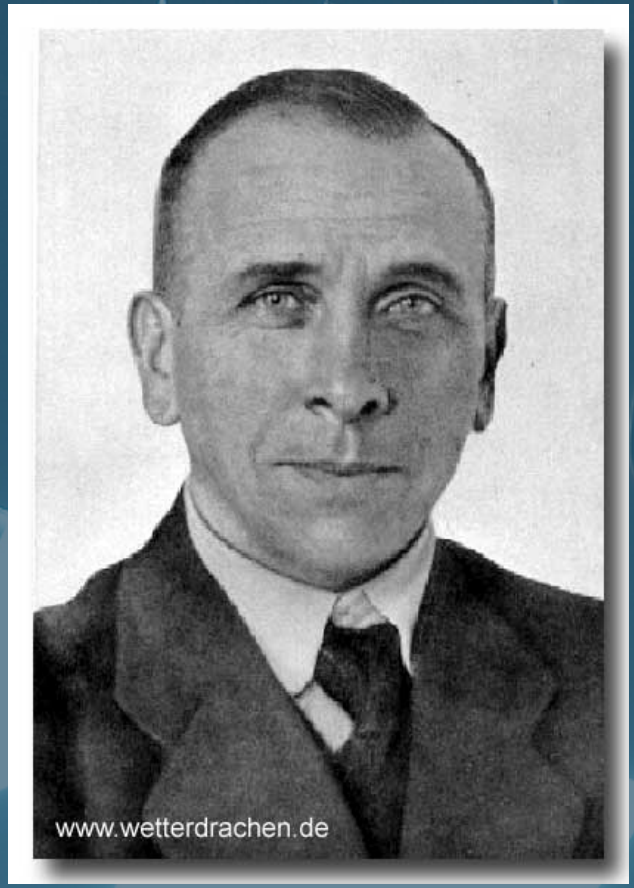
Plate Tectonics: The Unifying Theory



Continental Drift

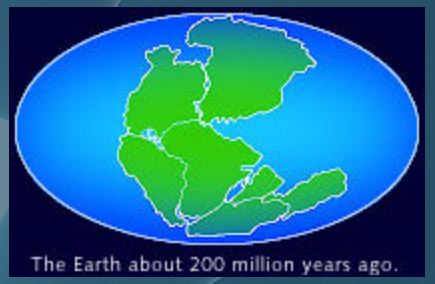
- The idea that continents appear as though they may fit together like pieces of a jigsaw puzzle came from looking at improved world maps
- In 1915, Alfred Wegener proposed his hypothesis of continental drift in his work *The Origins of Continents and Oceans*

Alfred Wegener



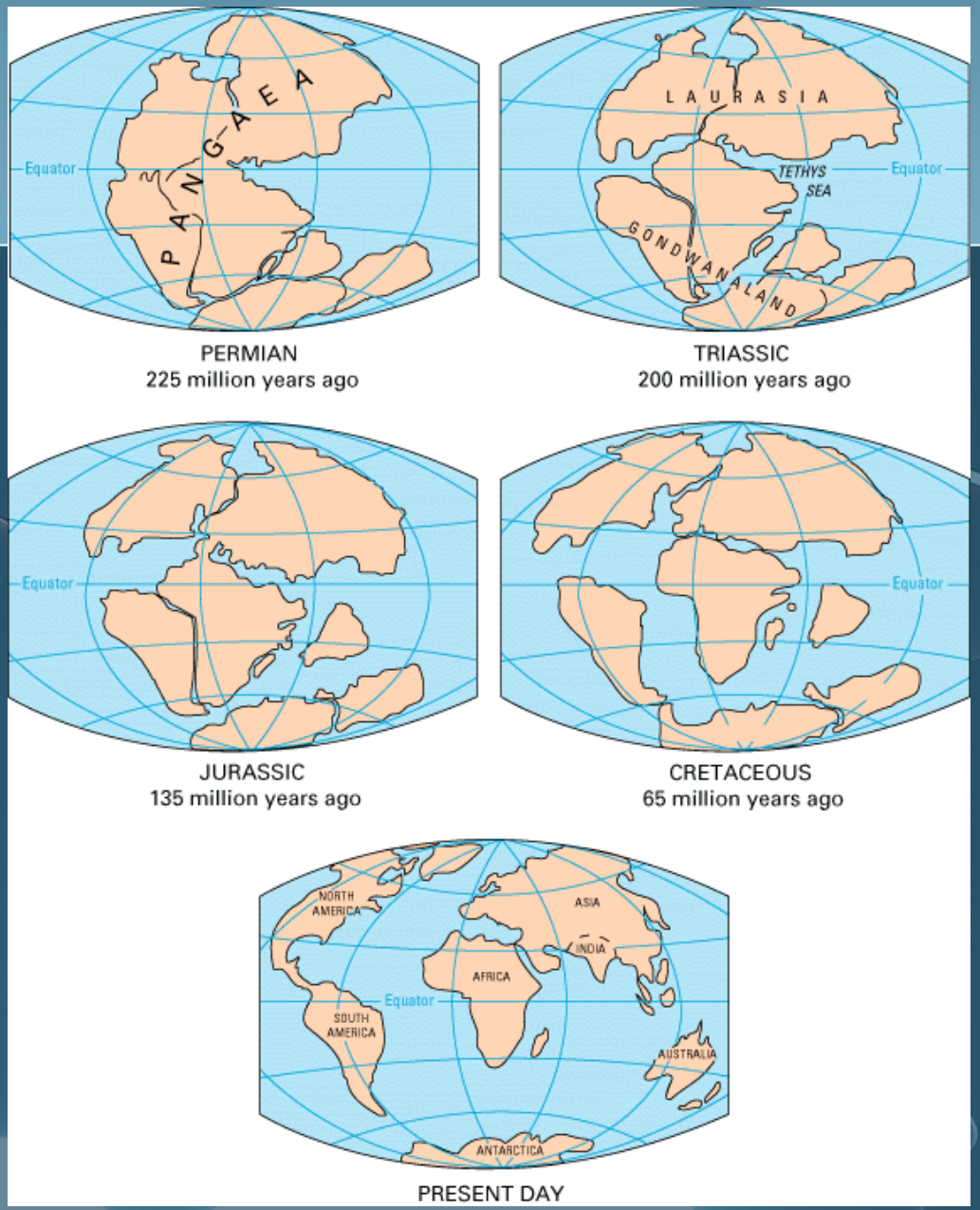
Continental Drift Continued…

- A supercontinent called Pangaea once existed and about 200 million years ago, it began to brake apart and drift into the continents' current positions
- Utilized four pieces of evidence
  - Puzzle fit
  - Distribution of fossils
  - Rock structures
  - Ancient climates


The Earth about 200 million years ago.


PANGAEA
Tethys Sea

Pangaea Supercontinent – 200 million years ago


PANGAEA
Equator
PERMIAN
225 million years ago
LAURASIA
TETHYS SEA
Equator
GONDWANALAND
TRIASSIC
200 million years ago
Equator
JURASSIC
135 million years ago
Equator
CRETACEOUS
65 million years ago
NORTH AMERICA
ASIA
INDIA
AFRICA
Equator
SOUTH AMERICA
AUSTRALIA
ANTARCTICA
PRESENT DAY

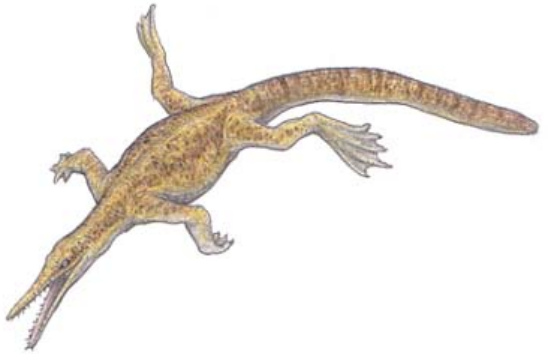
Continental Jigsaw Puzzle

- Coastlines of certain continents appears to be similar
  - South America and Africa
- Criticism: shorelines are modified by erosion
- Looking at the continental shelf gives us a better view of the true boundary (viewed at a depth of 900 meters)
  - See results in Figure 7.3 (overlaps caused by streams depositing sediments)

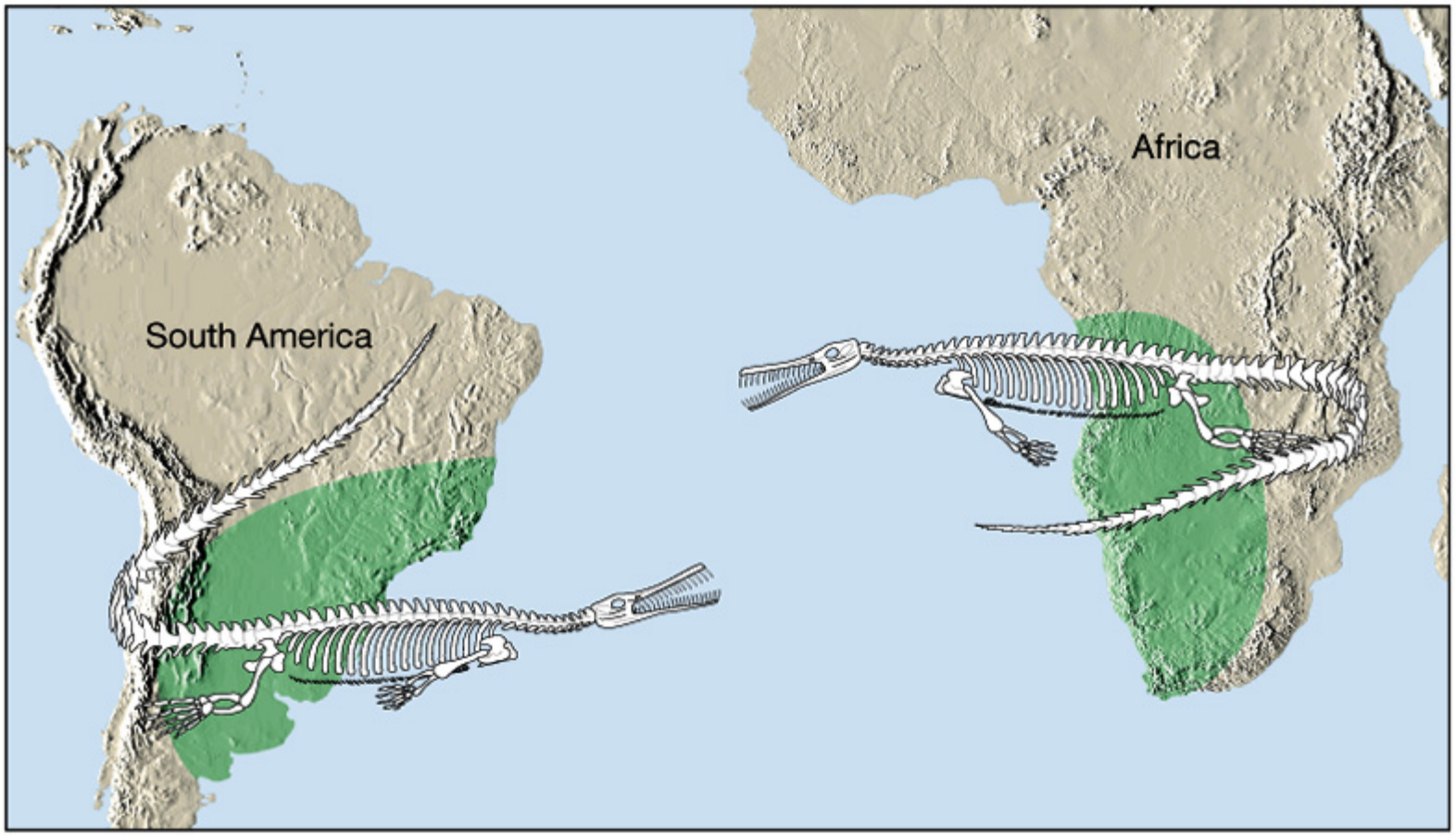
Distribution of Fossils

- Land connection was necessary to explain the existence of identical fossils on now widely separated continents
  - *Mesosaurus*
  - *Glossopteris*

Mesosaurus

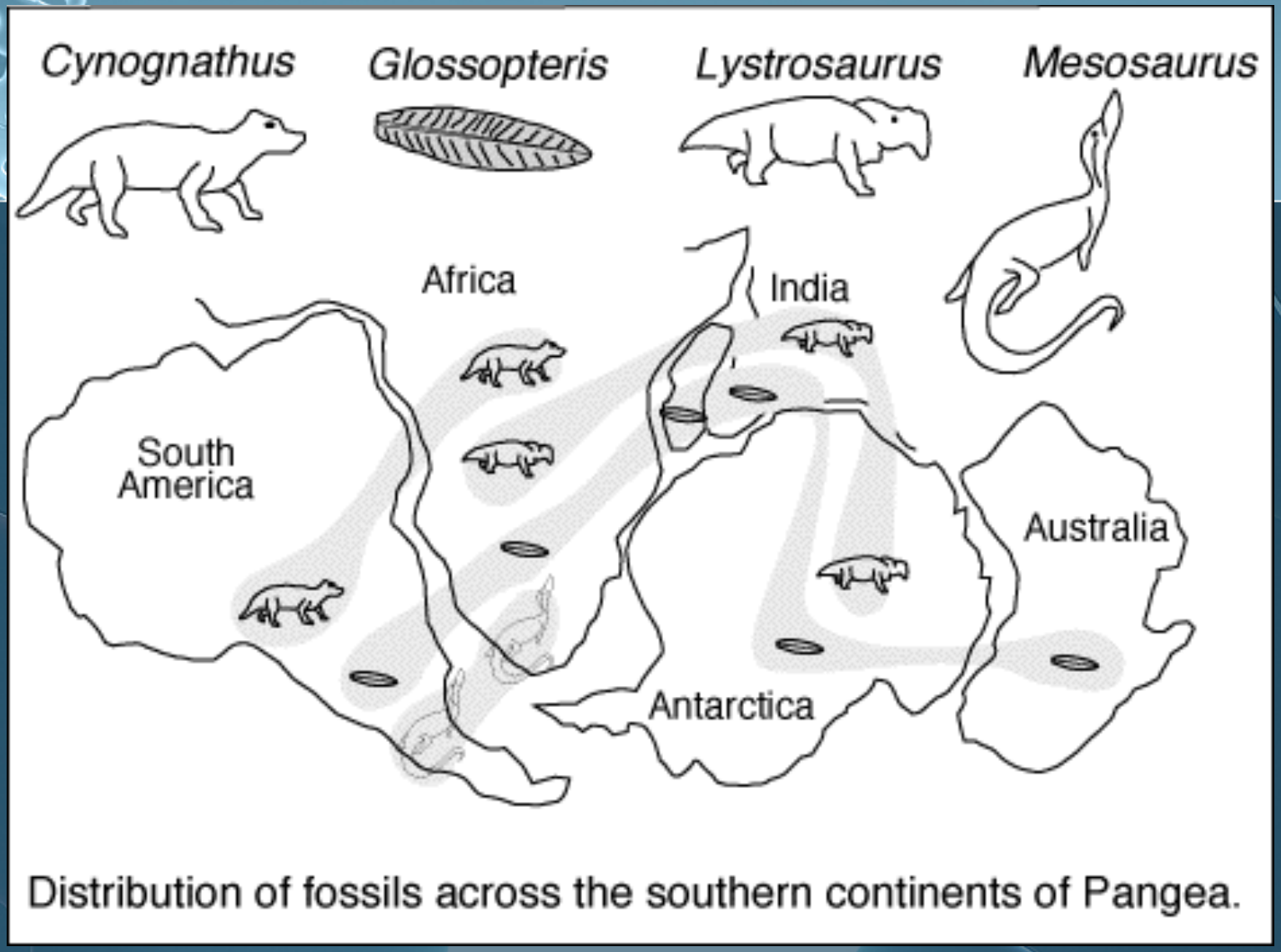


- Aquatic, snaggle-toothed reptile
- Remains found in eastern South America and Southern Africa
- It was theorized that if it was able to swim and cross the Atlantic Ocean, it's remains would be more widely distributed
- Criticism: land bridges (like during the ice age when sea levels rose and animals crossed the Bering Strait) (there are no remains of these below sea level though)

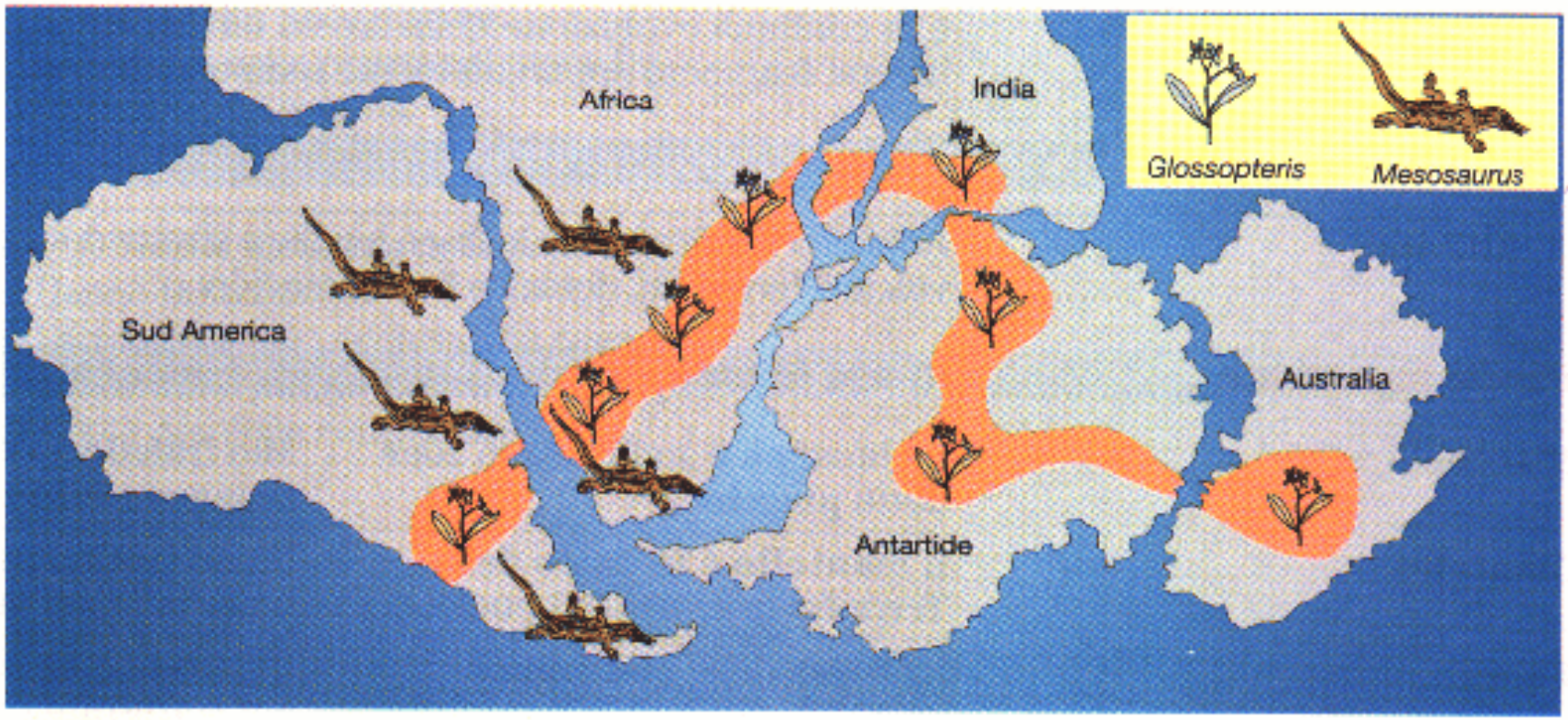

South America
Africa

Glossopteris

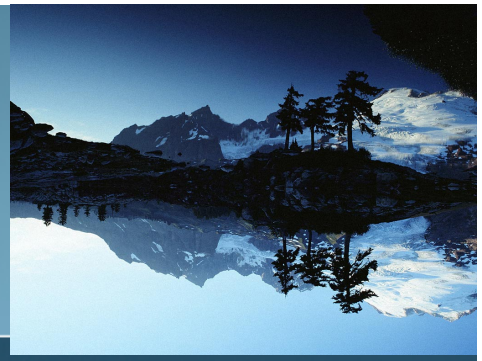
- Seed fern fossils found on many continents with very different climates today



Distribution of fossils across the southern continents of Pangea.


Africa
India
Glossopteris
Mesosaurus
Sud America
Australia
Antartide

Rock Structures



- Rocks found in a particular region on one continent closely match the age and type of those found on an adjacent continent in an adjacent position
  - Appalachians in the northeast US and Newfoundland and those in the British Isles and Scandinavia
  - See Figure 7.6 (assemble the mountains and they form a continuous belt)


Caledonian Mountains
British Isles
North America
Scandinavia
Appalachian Mountains
Africa
South America

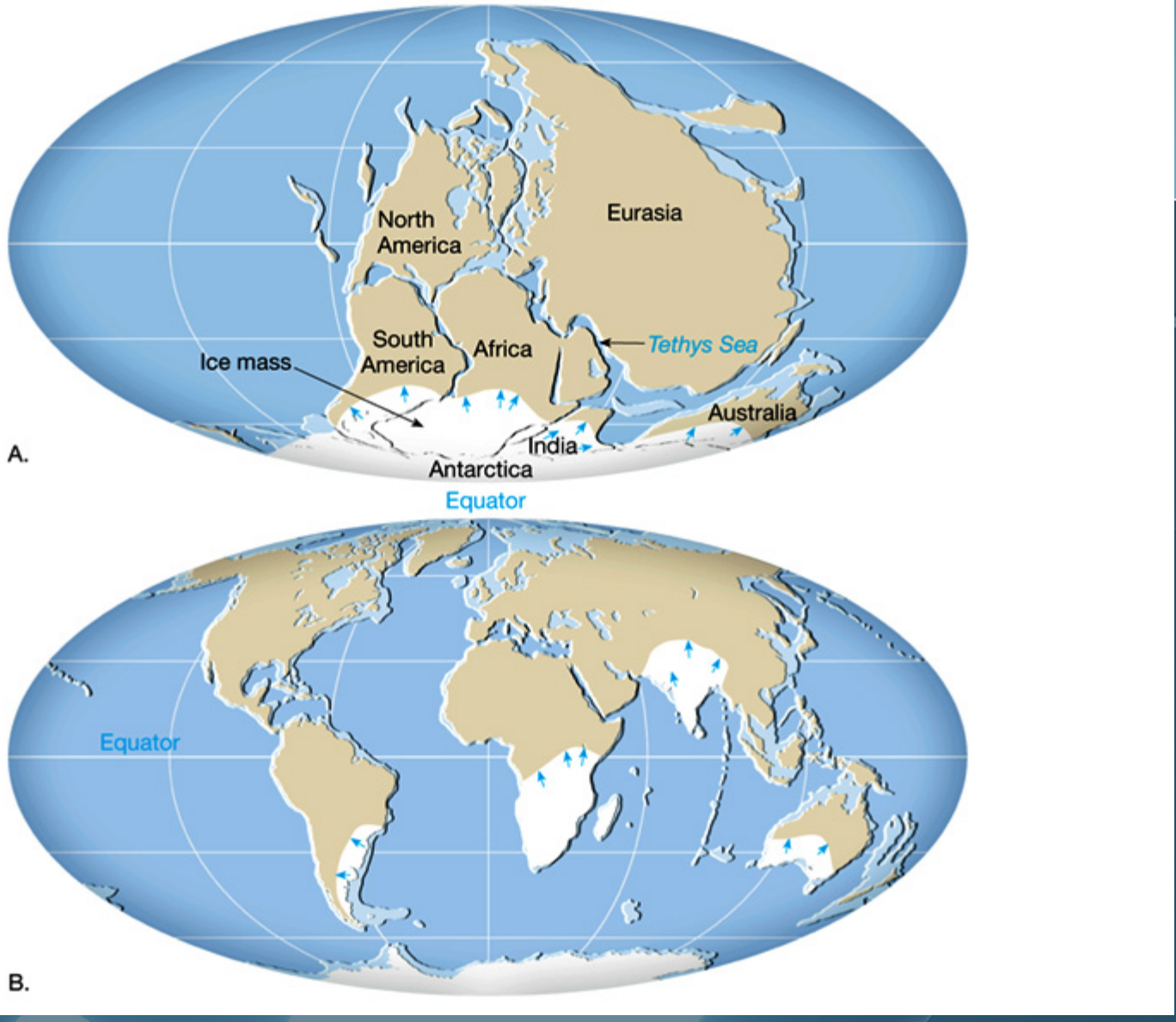
A.


Greenland
Europe
North America
Africa
South America

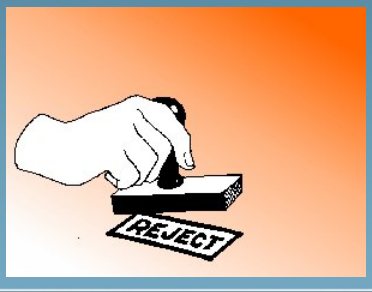
B.

Ancient Climates

- **Evidence of dramatic global climate change**
- **Wegener studies various sedimentary rocks to determine climate changes**
  - Coal deposits found in Antarctica (recall formed from swamp plants) → proves Antarctica once had a temperate (warm), rainy climate (would have been closer to the equator)
  - Glacial deposits found in Africa, India, Australia, and South America → proves area had once been covered by ice (would have been closer to south pole) (most of this land presently lies within 30 degrees of the equator)


North America
Eurasia
South America
Africa
Tethys Sea
Ice mass
Australia
India
Antarctica
A.
Equator
Equator
B.

Rejection



- **Wegener died in 1930 under hostile criticism**
- **2 major objections**
  - Couldn't explain the cause of the moving continents (Wegener thought maybe the rotation of Earth or tidal influence of the Moon but these were not strong enough)
  - Couldn't explain how they were moving without shattering (Wegener thought that the sturdy continents broke through weak ocean crust but no one knew if the ocean floor was weak enough to allow this to occur without shattering the continents)

Theory of Plate Tectonics

- Lithosphere: upper mantle and crust (strong)
- Covers weak region in mantle called asthenosphere
- The lithosphere is broken into enormous slabs called plates
- Plates move in different directions and at different rates over the surface and change in shape and size

Plates

- **Most include a continent and plus seafloor (different from Wegener's theory---he thought continents moved through the floor not with it)**
- **Seven Large (move about 5cm/y)**
  - North American
  - South American
  - Pacific (largest)
  - African
  - Eurasian
  - Australian-Indian
  - Antarctic

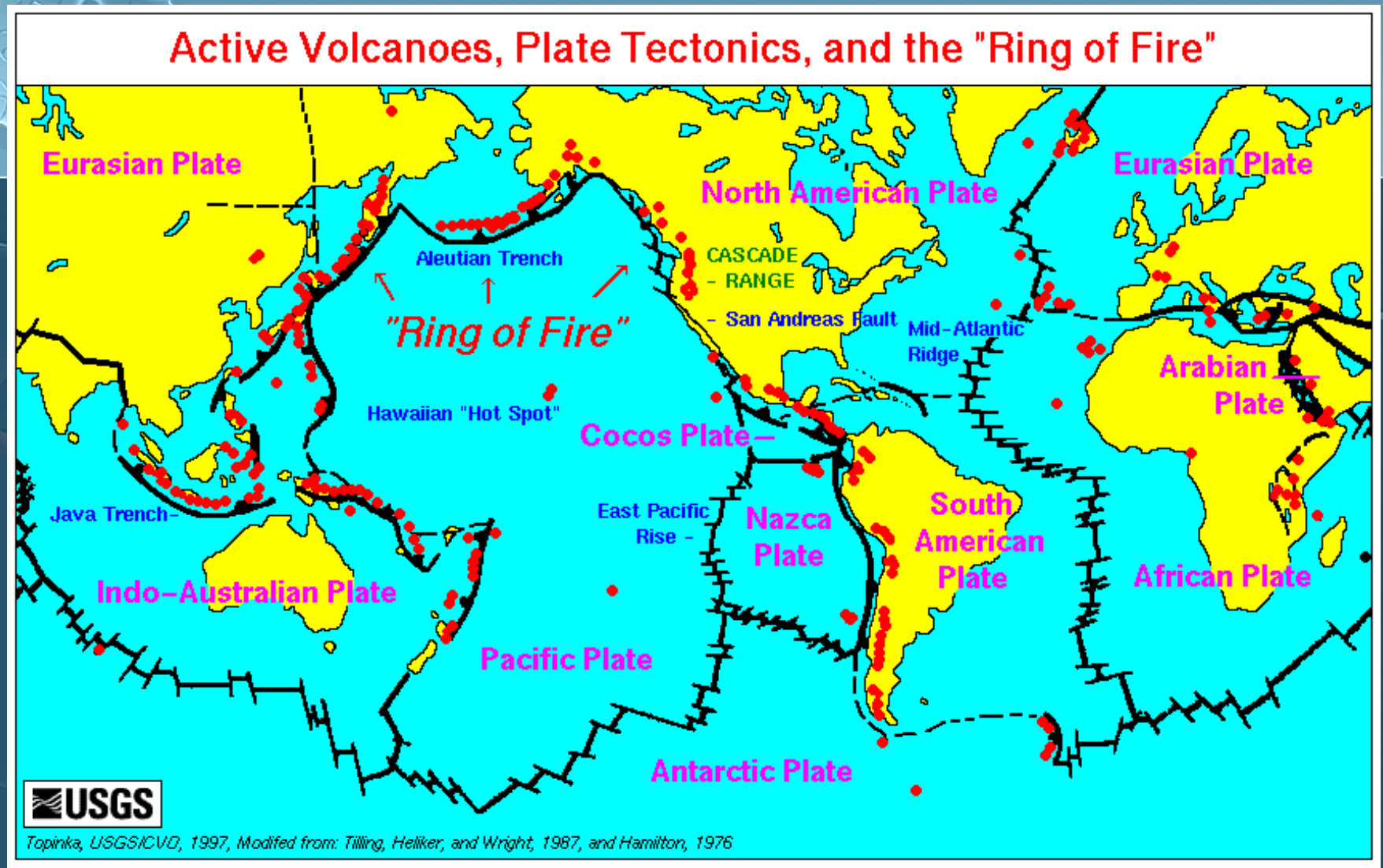

Active Volcanoes, Plate Tectonics, and the "Ring of Fire"
Eurasian Plate
North American Plate
Eurasian Plate
Aleutian Trench
CASCADE
- RANGE
- San Andreas Fault
"Ring of Fire"
Mid-Atlantic
Ridge
Arabian
Plate
Hawaiian "Hot Spot"
Cocos Plate
Java Trench
East Pacific
Rise
Nazca
Plate
South
American
Plate
African Plate
Indo-Australian Plate
Pacific Plate
Antarctic Plate
USGS
Topinka, USGS/CVO, 1997, Modified from: Tilling, Heliker, and Wright, 1987, and Hamilton, 1976

Plate Boundaries

- All interactions among plates occur along their boundaries (earthquakes, volcanoes, etc.)
- Three types
  - Divergent
  - Convergent
  - Transform

- Each plate is a combo of all 3 types
- Plates may shrink or grow in an area depending on types present (see pg. 199)

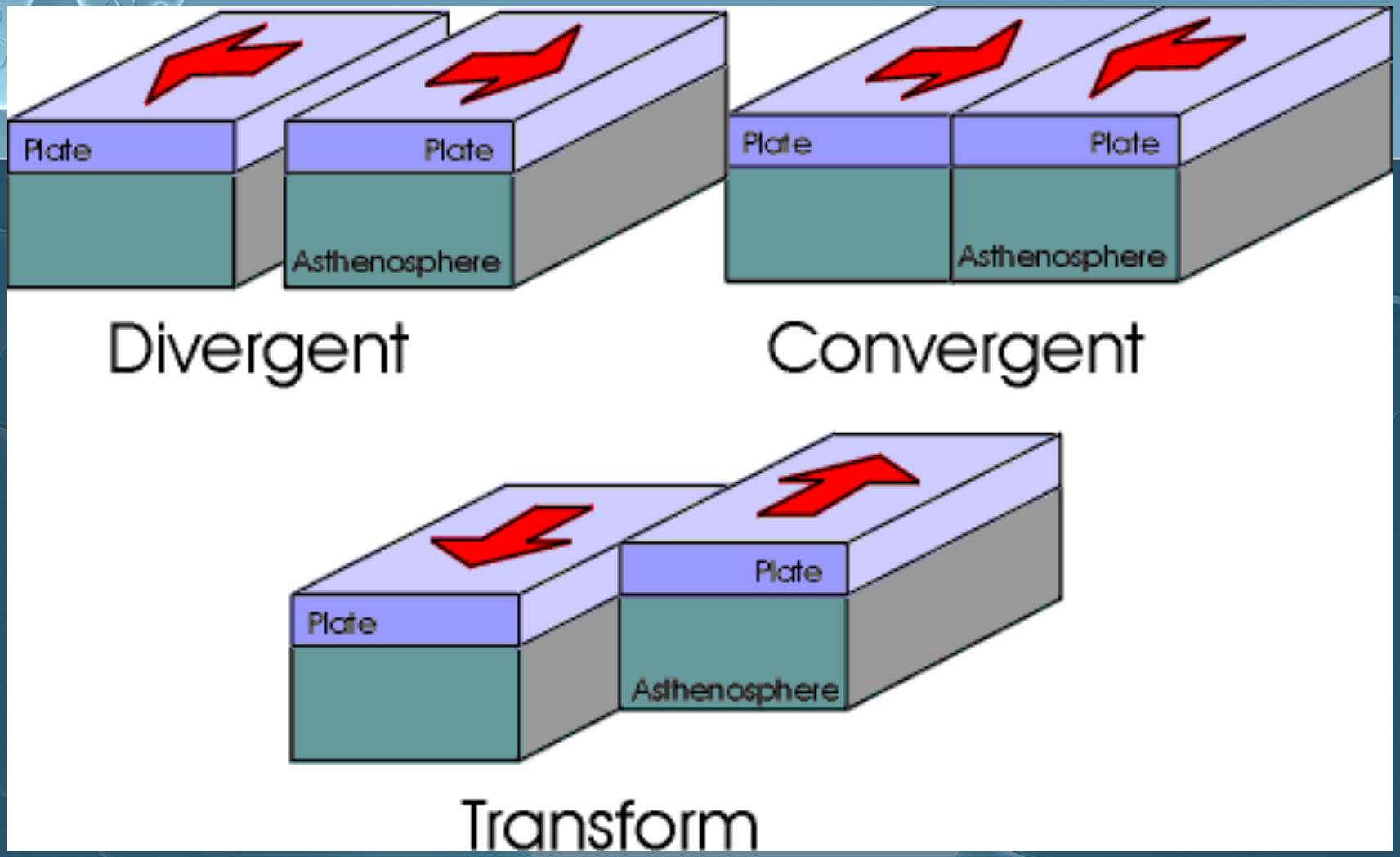
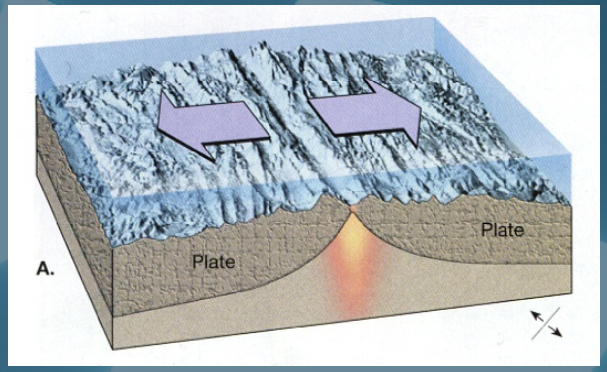


Plate
Plate
Asthenosphere
Divergent
Plate
Plate
Asthenosphere
Convergent
Plate
Plate
Asthenosphere
Transform

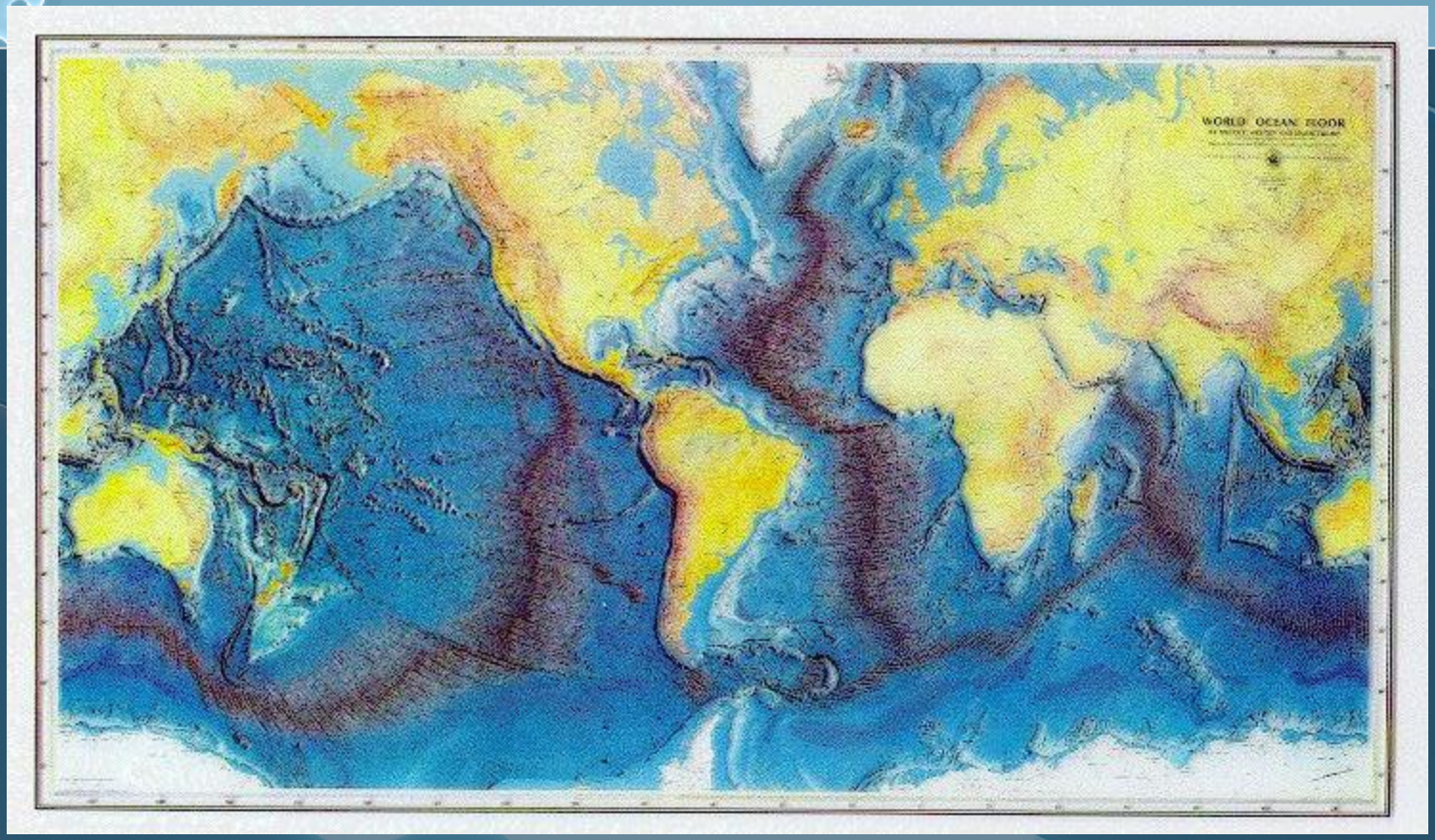
Divergent Boundaries

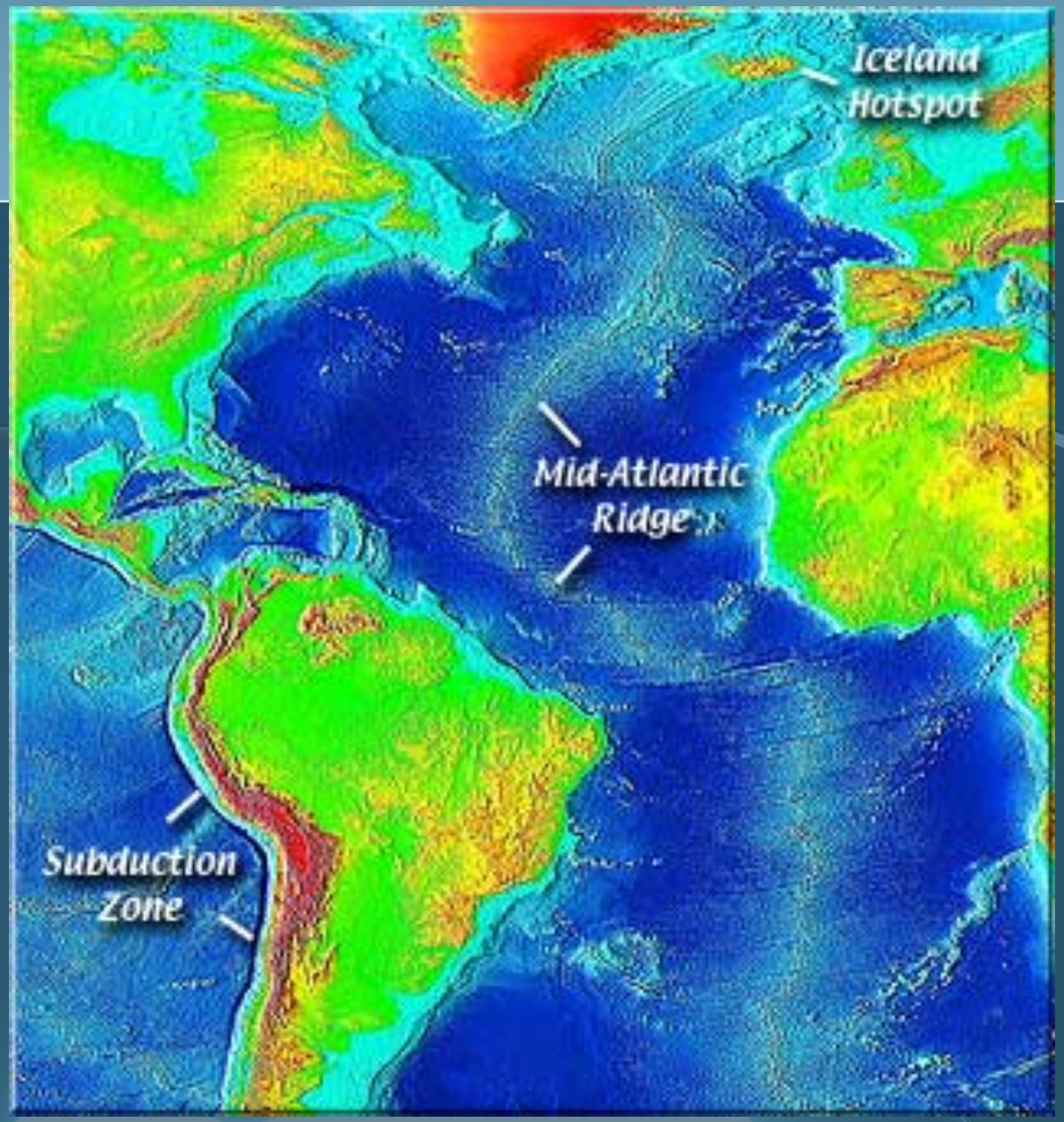
- Also called constructive margins
- Two plates move apart
- Results in upwelling of material from mantle to create new seafloor



Divergent Continued…

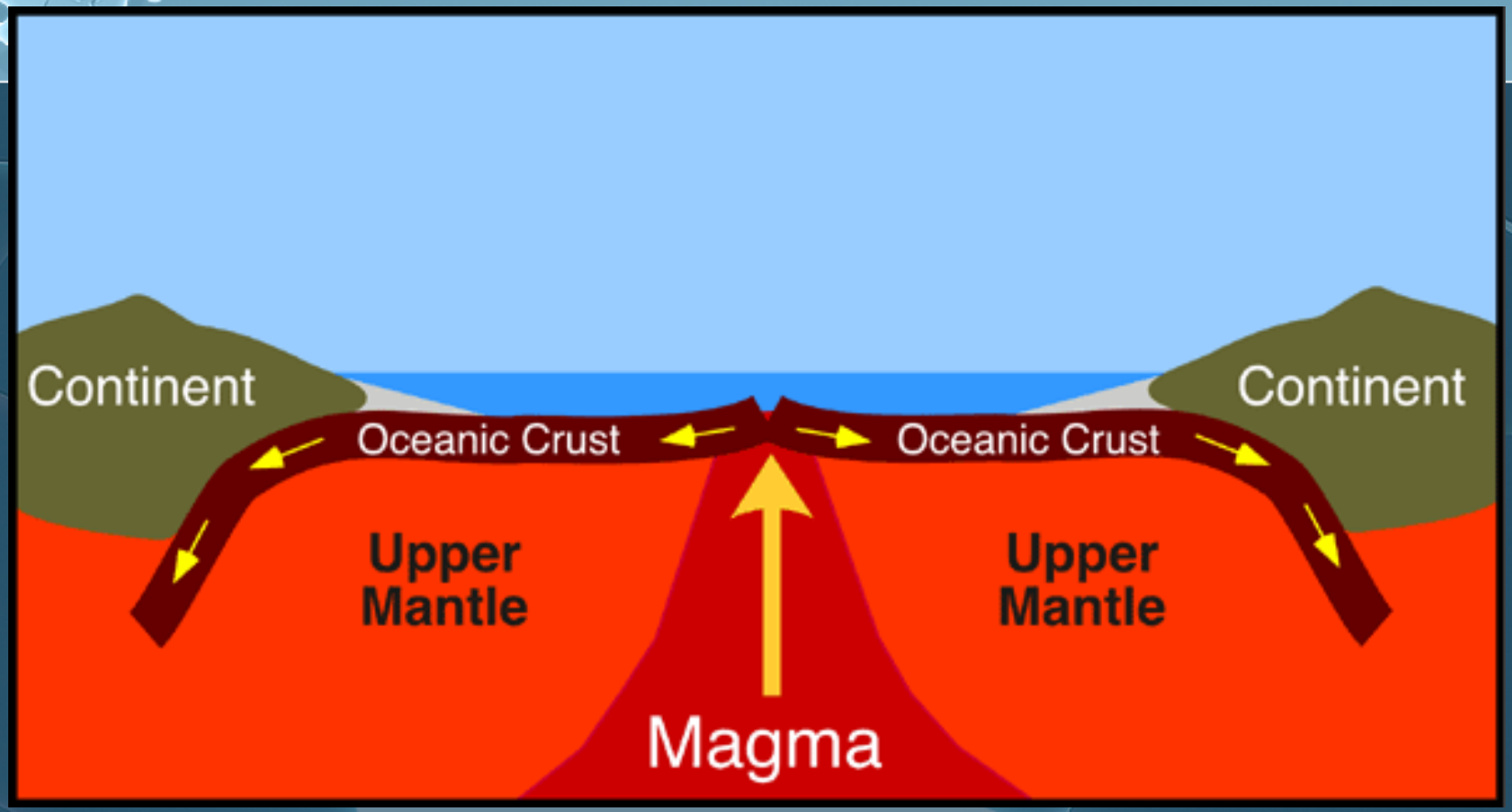
- Along divergent plate boundaries, the ocean floor is elevated forming oceanic ridges (most well known is the Mid-Atlantic Ridge)
- Oceanic ridge---longest topographical feature on Earth's surface (winds through all ocean basins like the seams of a baseball)
- Along the axis are deep faulted structures called rift valleys


WORLD OCEAN FLOOR


Iceland
Hotspot
Mid-Atlantic
Ridge
Subduction
Zone

Seafloor Spreading

- Along the oceanic ridge, the process of seafloor spreading takes place (creation of new seafloor) (5 cm/y on average…2 cm/y in the Atlantic and 15 cm/ y in the Pacific)
- Process
  - Magma forced up towards the crust along an ocean ridge and fills the gap created (because it is less dense than the surrounding material)
  - Magma hardens and a small amount of new ocean floor is added on both sides of the ridge symmetrically)
  - Continues and each new part moves away from the ridge


Continent
Continent
Oceanic Crust
Oceanic Crust
Upper Mantle
Upper Mantle
Magma

Rifting and Seafloor Spreading

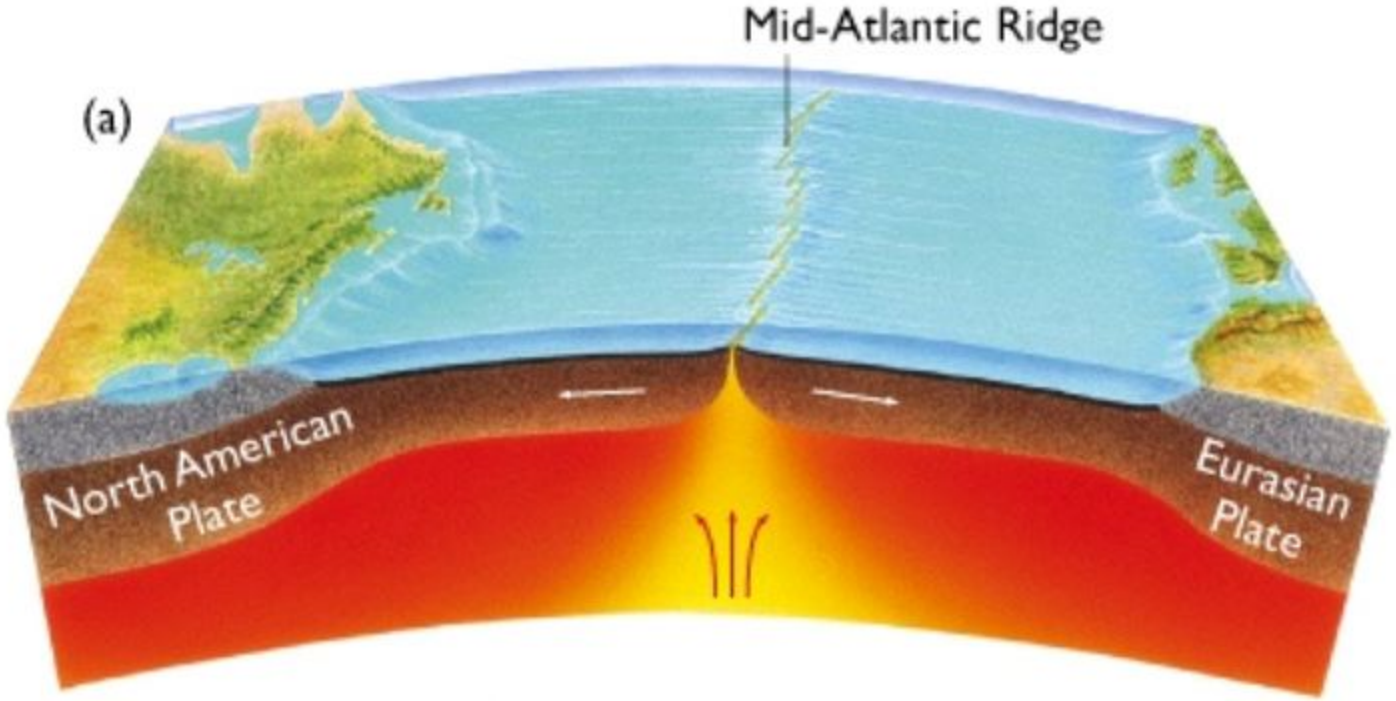
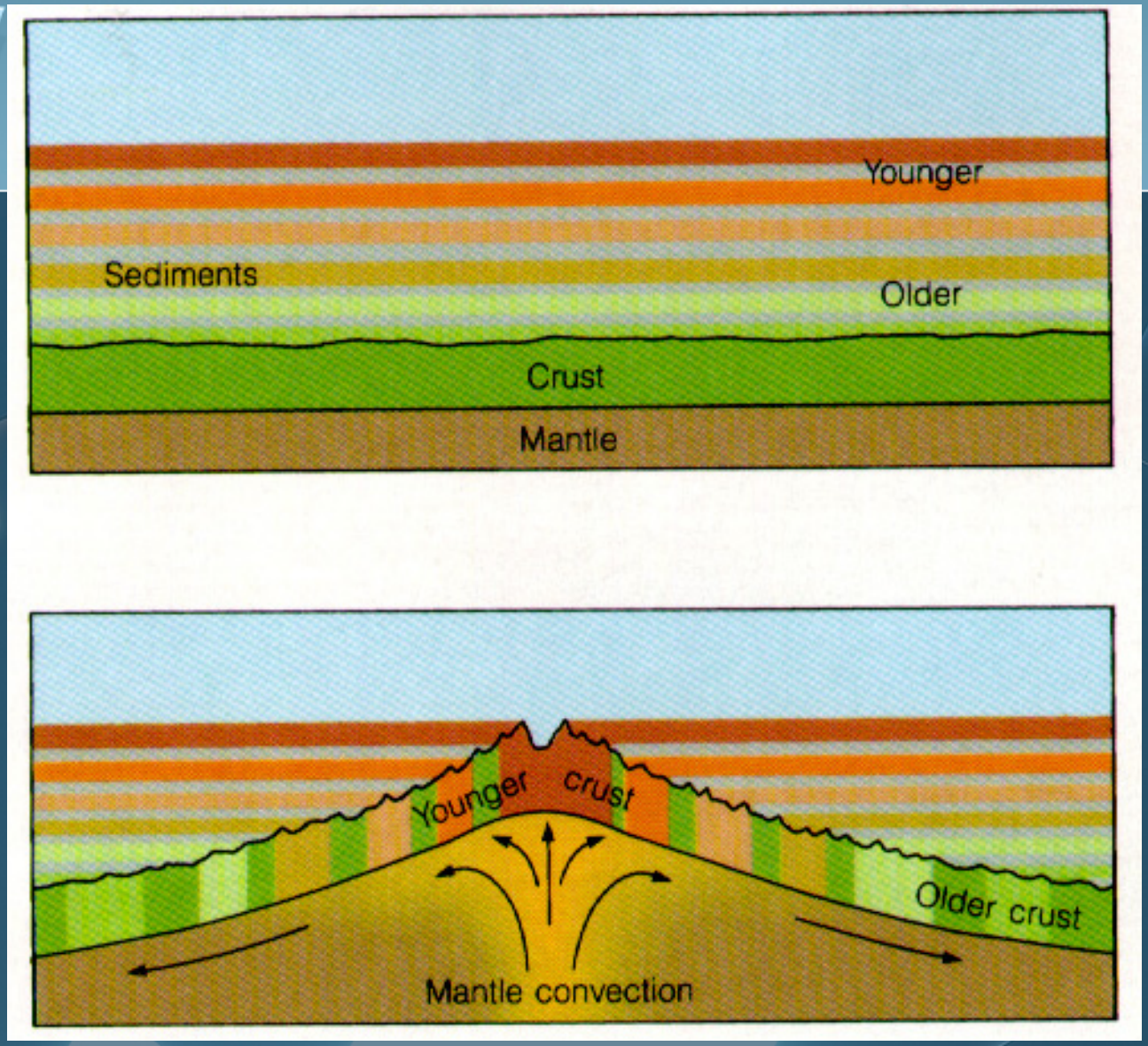
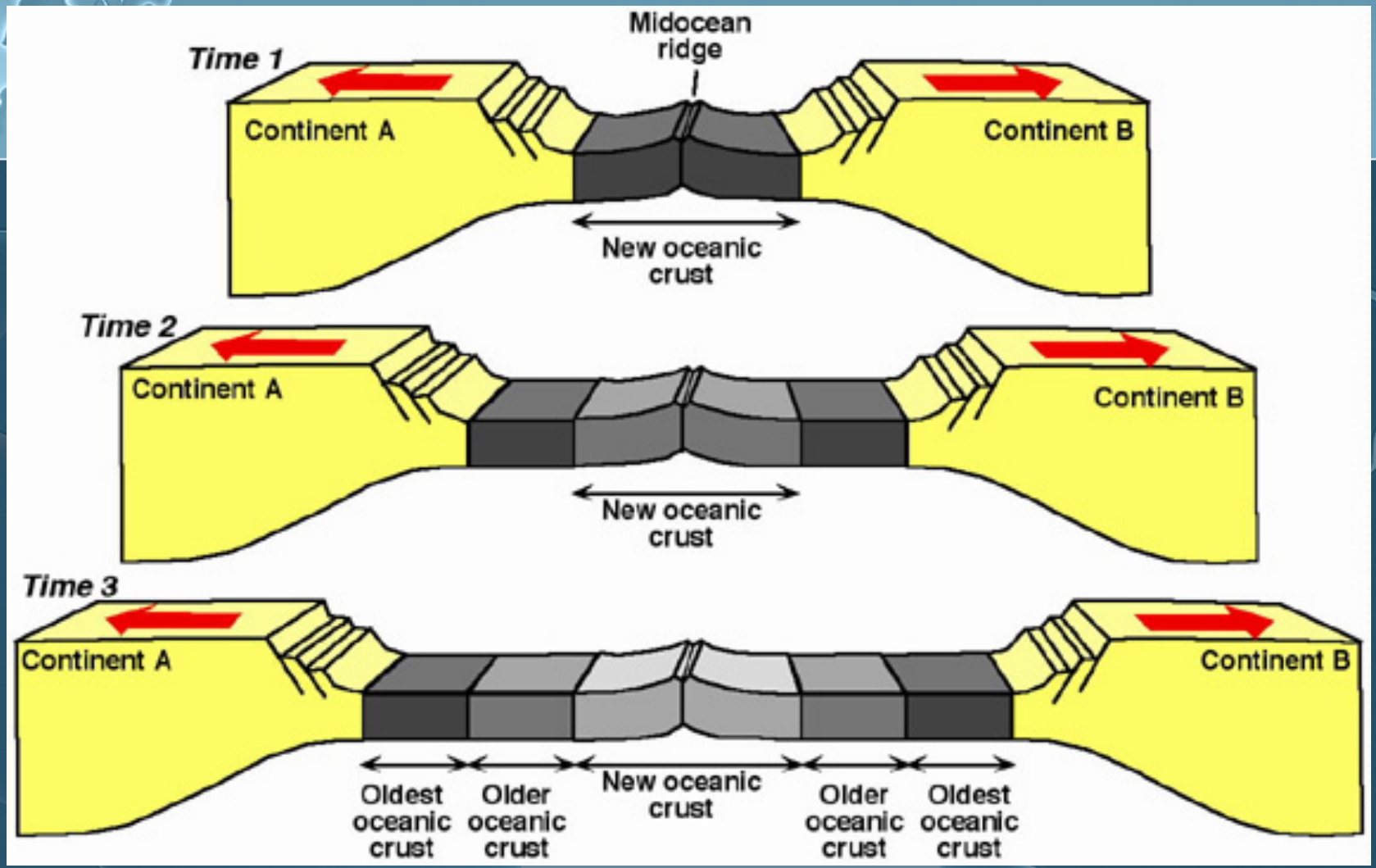


Fig. 20.4a

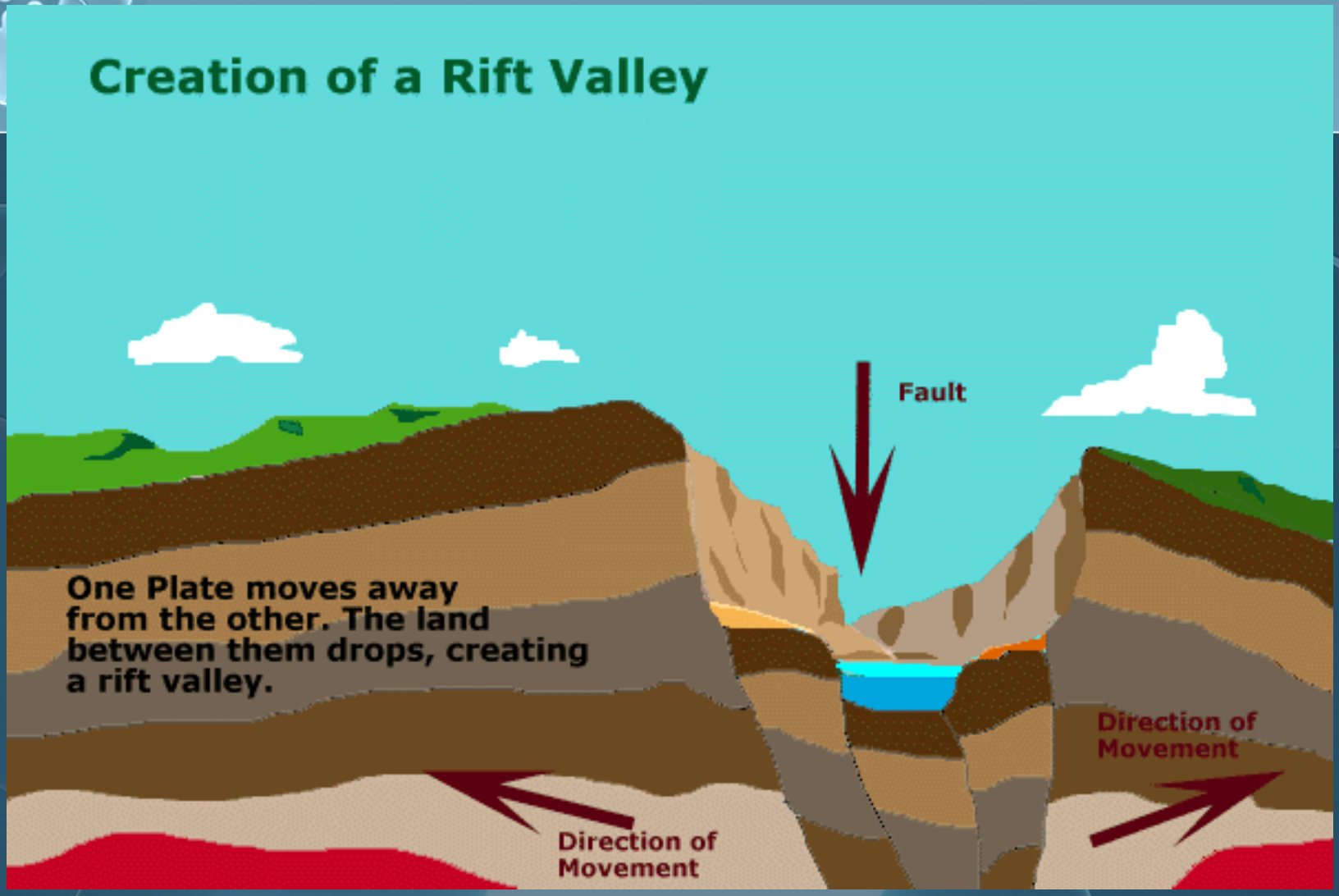

Younger
Sediments
Older
Crust
Mantle
Younger crust
Older crust
Mantle convection


Time 1
Midocean ridge
Continent A
Continent B
New oceanic crust
Time 2
Continent A
Continent B
New oceanic crust
Time 3
Continent A
Continent B
Oldest oceanic crust
Older oceanic crust
New oceanic crust
Older oceanic crust
Oldest oceanic crust

Continental Rifts

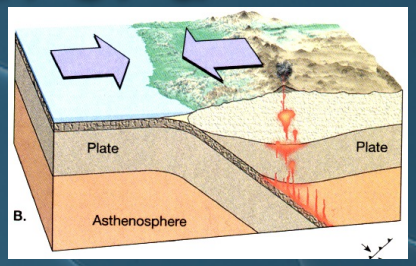
- Spreading centers that develop within a continent which cause land to split (as in the case of Pangaea)
- Present day examples:
  - East African rift valley
  - Rio Grande Rift

Creation of a Rift Valley



Convergent Boundaries

- Also called destructive margins
- Two plates move together
- Results in oceanic lithosphere being thrust beneath an overriding plate, which gets reabsorbed into the mantle (subduction) or if 2 continental plates collide, results in the formation of a mountain



Convergent Continued…

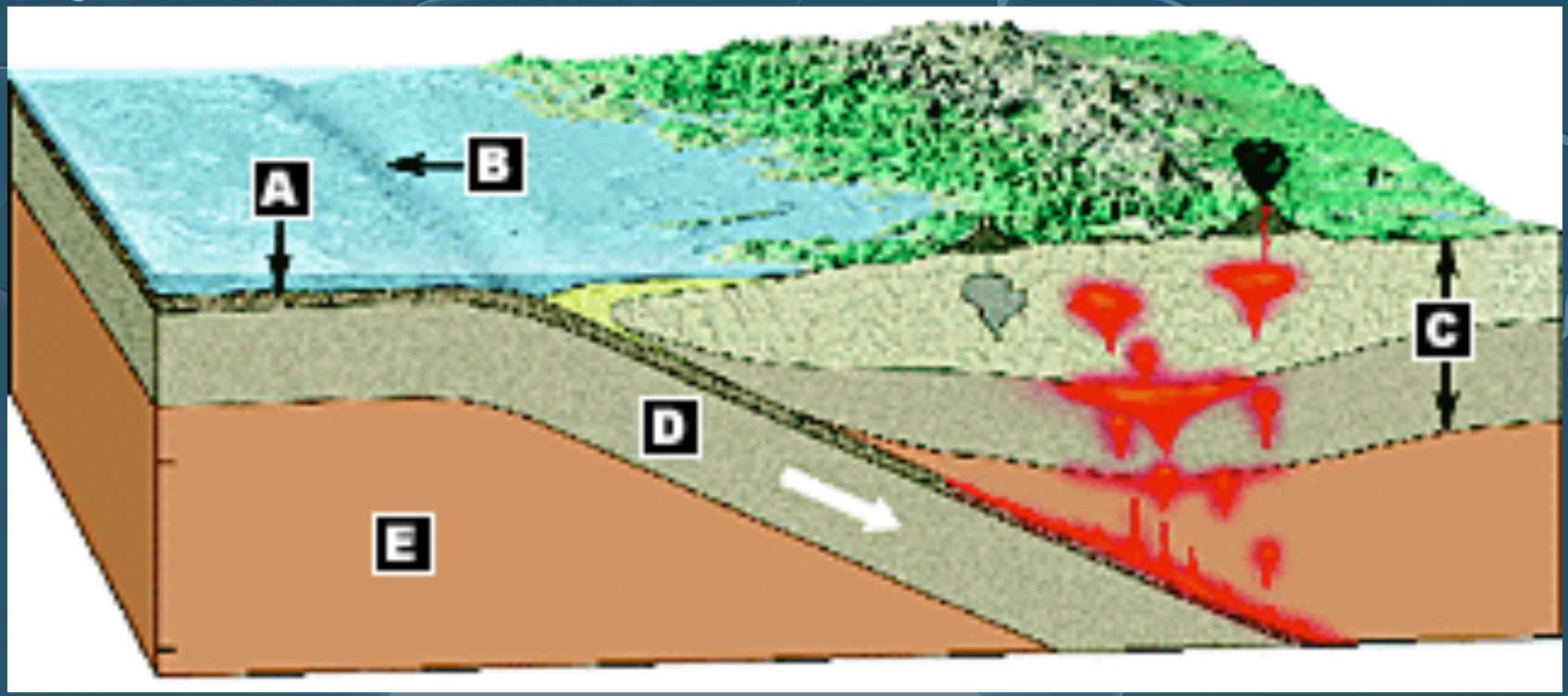
- To accommodate the new lithosphere, older parts of the lithosphere (oceanic) are returning to the mantle along convergent boundaries
- As two plates converge, the edge of one is bent downward, allowing it to slide beneath the other forming a trench: subduction zones (angles range from a few degrees to 90 degrees: determines strength of earthquakes present along boundaries) (see top of pg. 207)

Convergent Continued…

- Three types (classified by what type of crust involved)
  - Oceanic crust converges with oceanic crust
  - Oceanic crust (mostly basalt) converges with continental crust (mostly granite and sedimentary rock)
  - Continental crust converges with continental crust

Oceanic to Continental

- Buoyant continental plate remains floating and the denser oceanic plate subducts (sinks into asthenosphere)
- May cause volcanic eruptions to occur
- Continental volcanic arcs: mountains (ex: Andes and Cascade Range in Washington, Oregon, and California) which are partially produced by volcanic activity (like Mt. St. Helens) associated with the subduction of oceanic lithosphere


A
B
C
D
E

Parts of an Ocean–Continent Convergent Plate Boundary

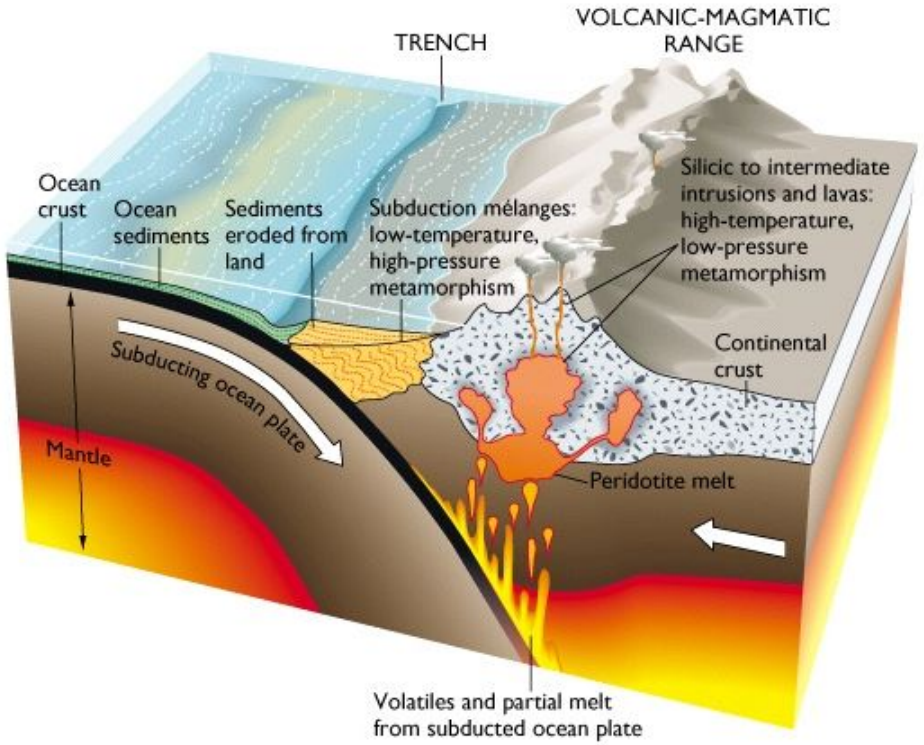
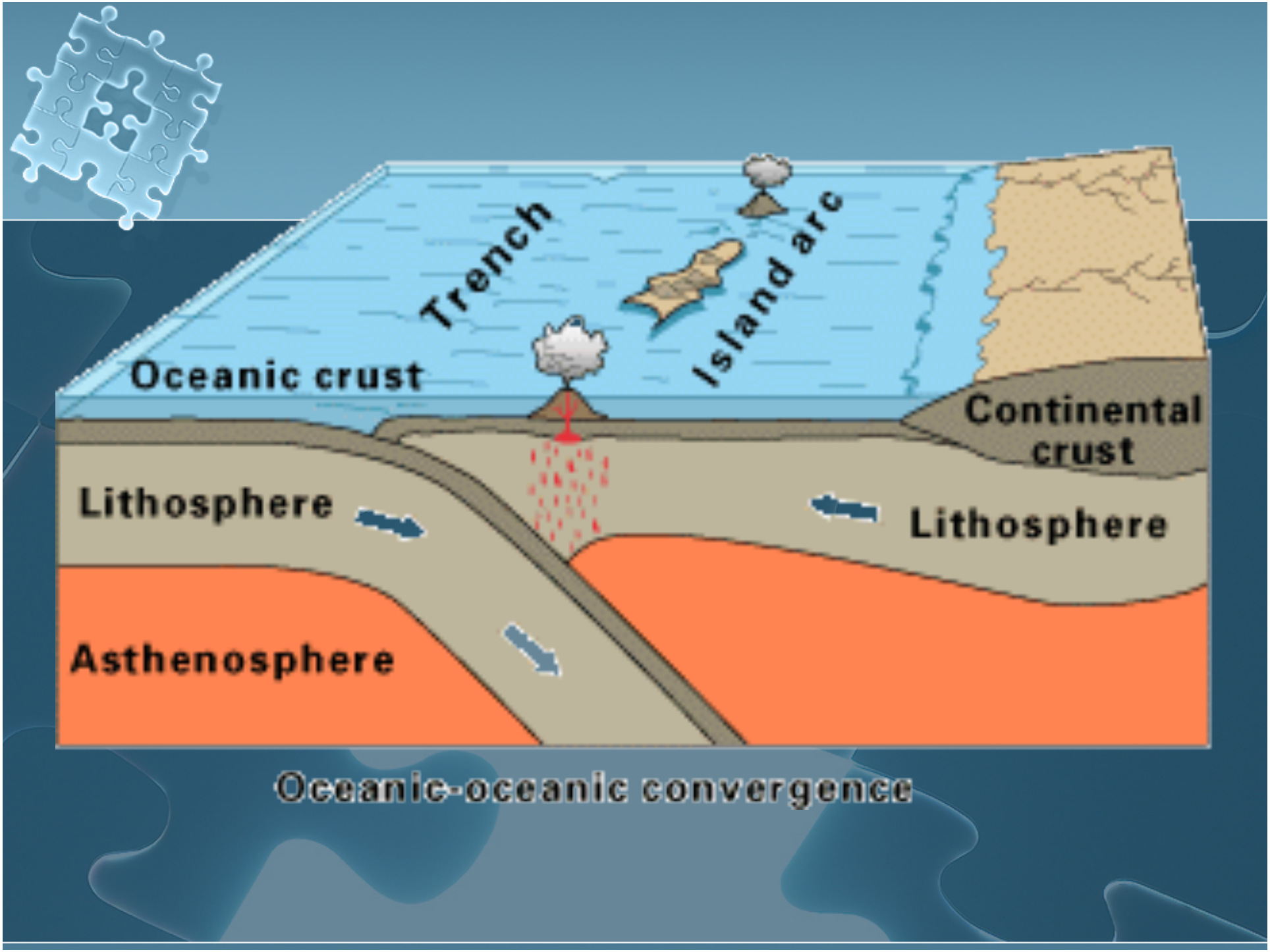


Fig. 20.19

Oceanic to Oceanic

- One oceanic plate descends beneath the other, kicking off volcanic activity just like the former boundary
- Here volcanoes form on the ocean floor though
- Forms volcanic island arcs


Trench
Island arc
Oceanic crust
Continental crust
Lithosphere
Lithosphere
Asthenosphere
Oceanic-oceanic convergence

Parts of an Ocean–Ocean Convergent Plate Boundary

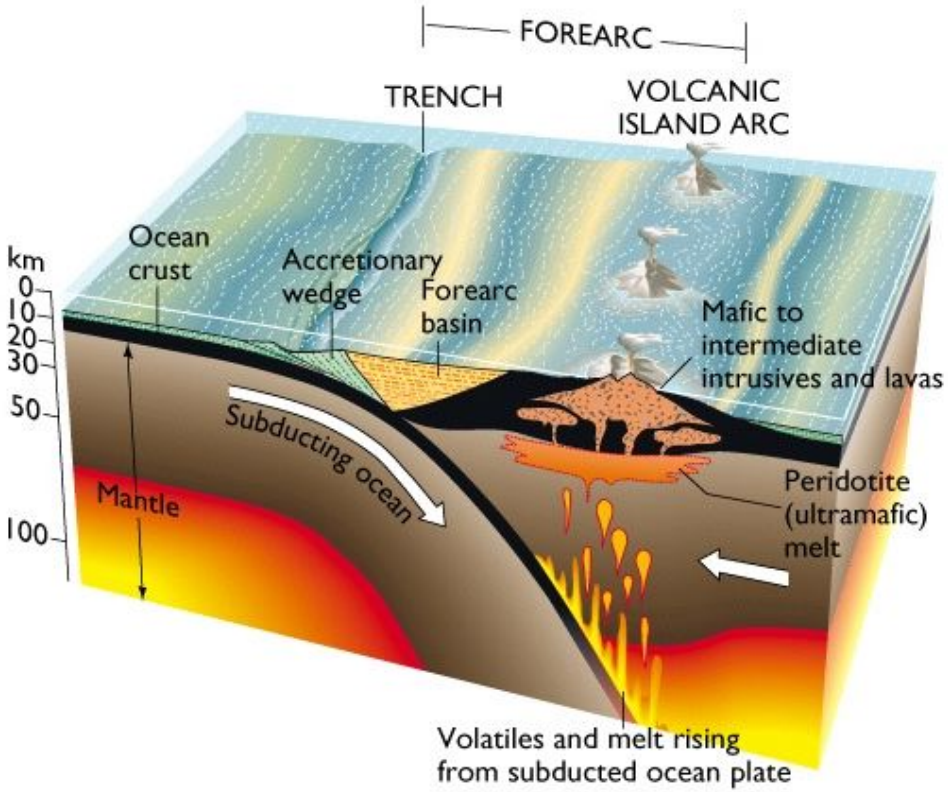
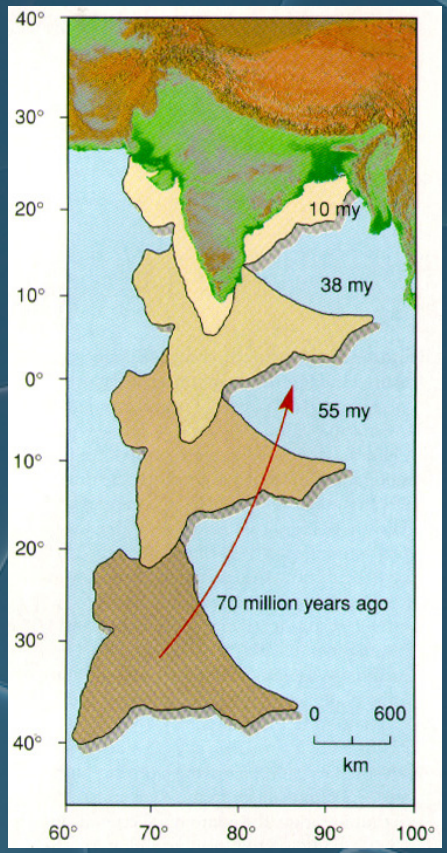
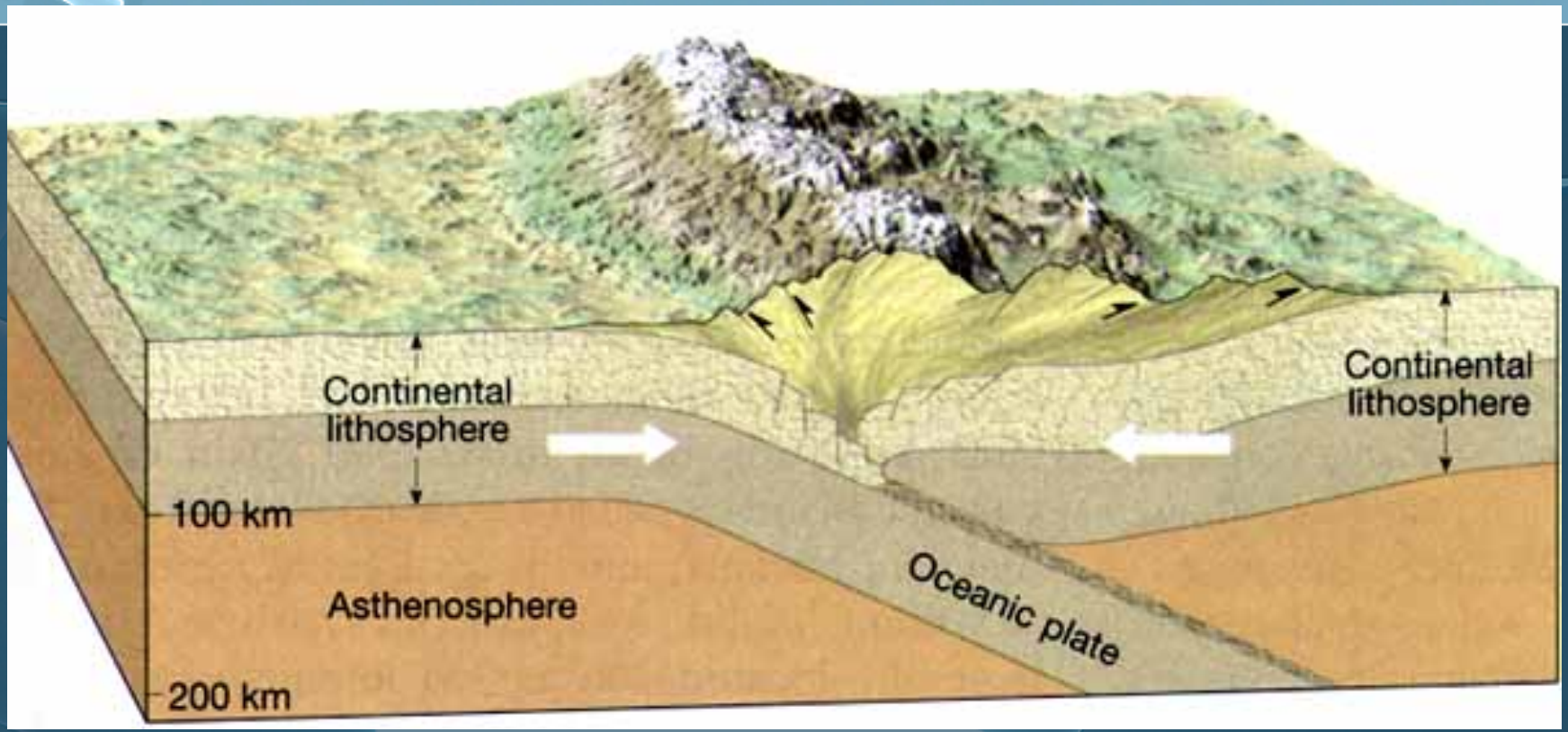


Fig. 20.18

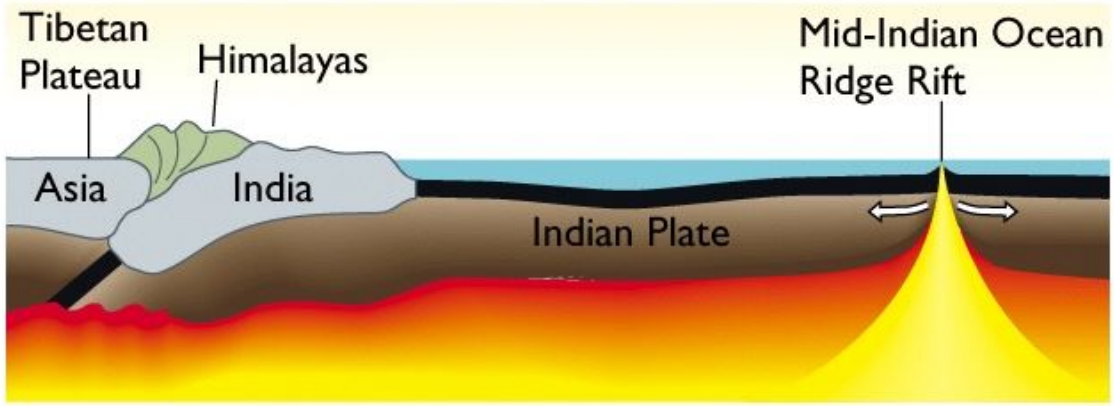
Continental to Continental

- Collision between two continental plates
- Examples
  - India collided with Asia and produced the Himalayas (see figure 7.14 on pg. 209)
  - Alps
  - Appalachians




Continental lithosphere
Continental lithosphere
100 km
Asthenosphere
Oceanic plate
200 km

Continent–Continent Convergent Boundary



(d)

Fig. 20.d

Convergent Plate Boundaries

Ocean - Continent

Continent - Continent

Ocean - Ocean

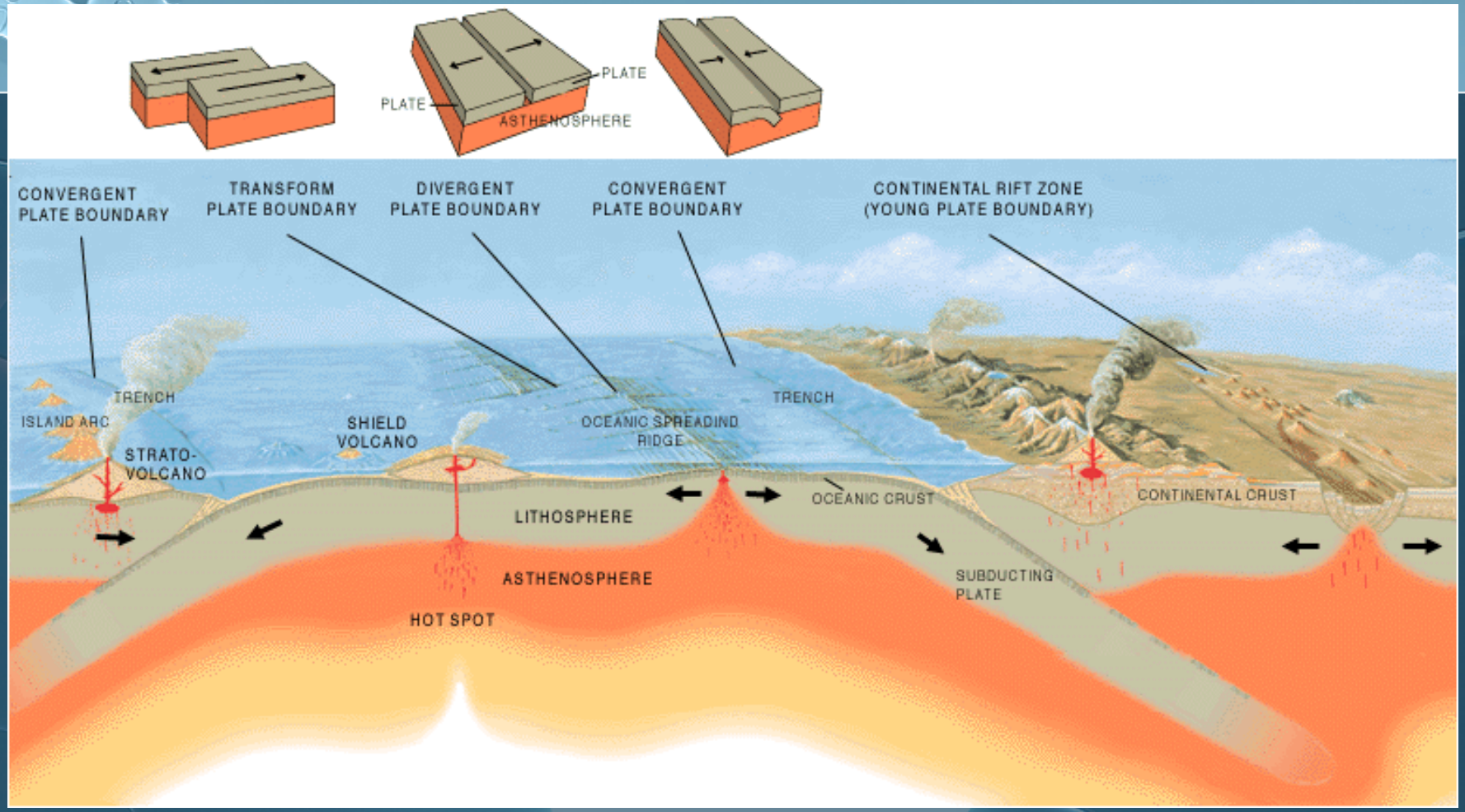
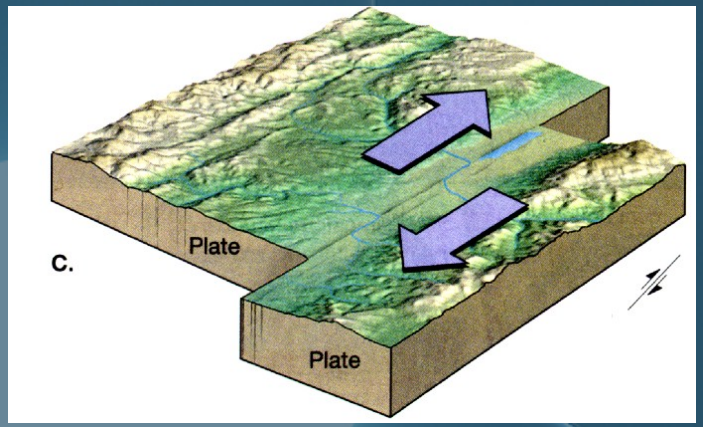


PLATE
PLATE
ASTHENOSPHERE
CONVERGENT PLATE BOUNDARY
TRANSFORM PLATE BOUNDARY
DIVERGENT PLATE BOUNDARY
CONVERGENT PLATE BOUNDARY
CONTINENTAL RIFT ZONE (YOUNG PLATE BOUNDARY)
TRENCH
ISLAND ARC
STRATO-VOLCANO
SHIELD VOLCANO
OCEANIC SPREADIND RIDGE
TRENCH
OCEANIC CRUST
CONTINENTAL CRUST
LITHOSPHERE
ASTHENOSPHERE
HOT SPOT
SUBDUCTING PLATE

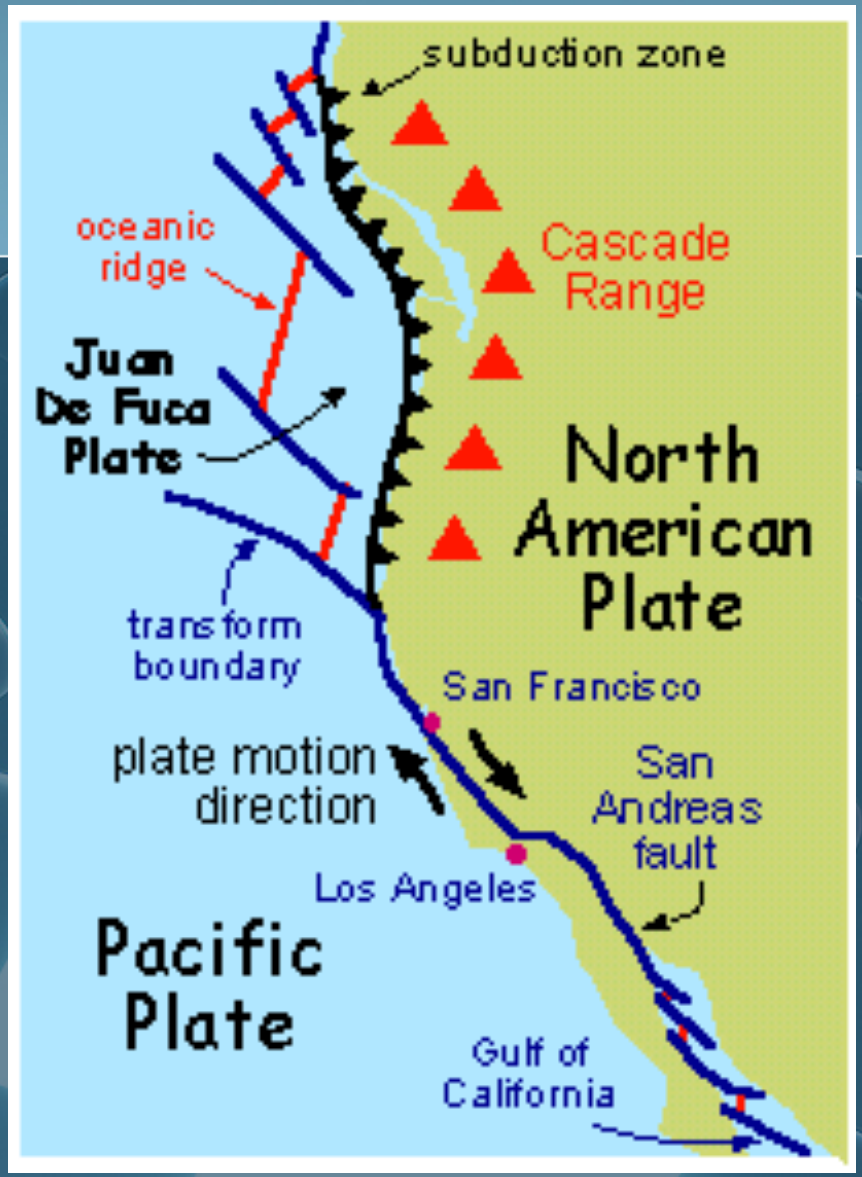
Transform Boundaries

- Also called conservative margins
- Two plates grind past each other without the production or destruction of lithosphere

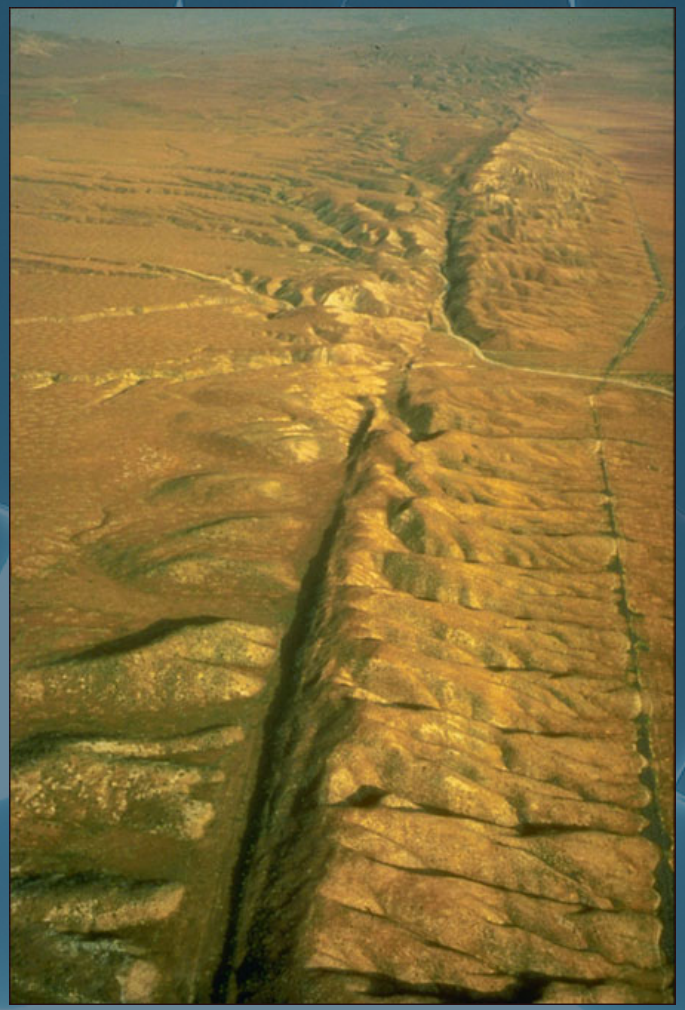


Transform Continued…

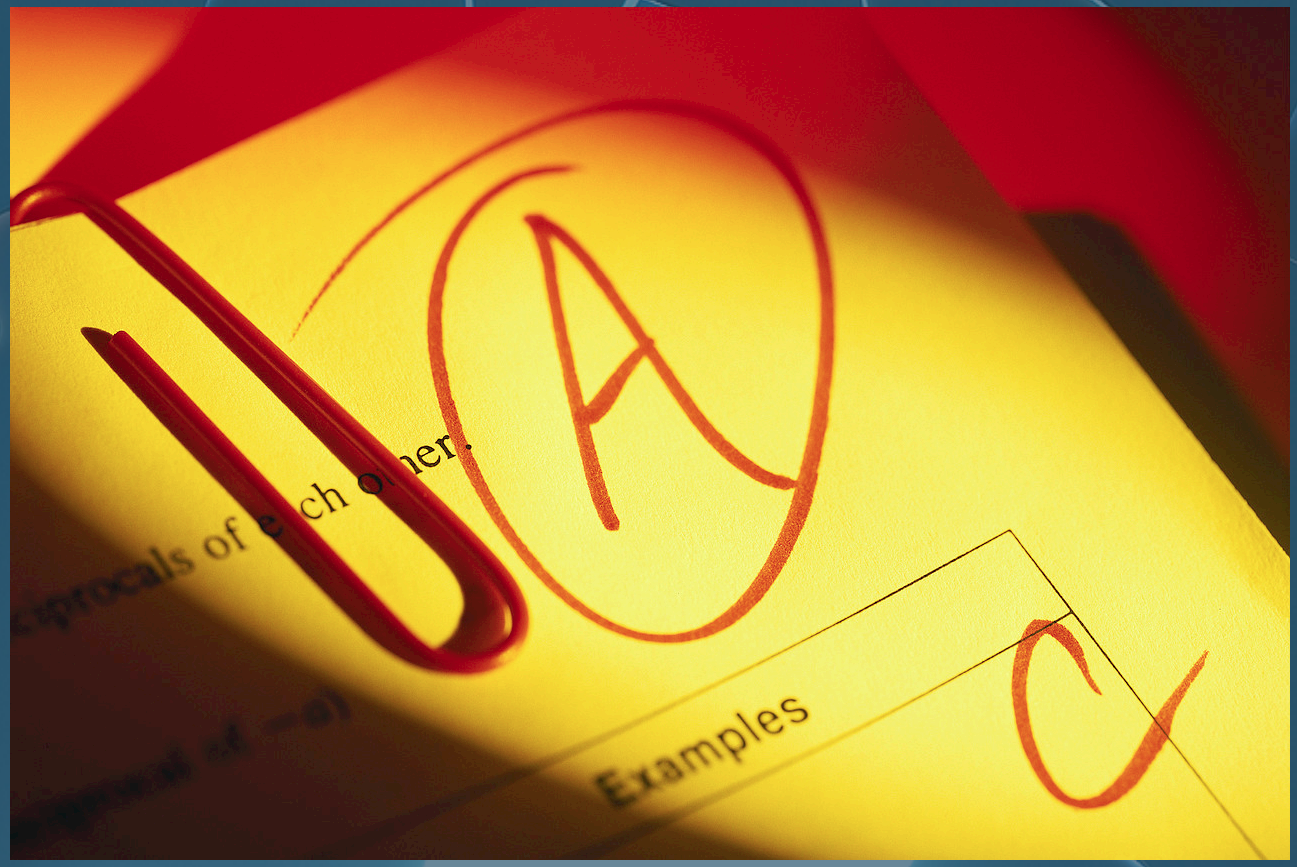
- Characterized by long faults and earthquakes
- Most occur on sea floor
- One famous exception is the San Andreas Fault in CA
  - Here, the Pacific plate is moving toward the northwest, past the North American plate…if it continues, Ca west of the fault zone will become an island


subduction zone
oceanic ridge
Cascade Range
Juan De Fuca Plate
North American Plate
transform boundary
San Francisco
plate motion direction
San Andreas fault
Los Angeles
Pacific Plate
Gulf of California

San Andreas Fault

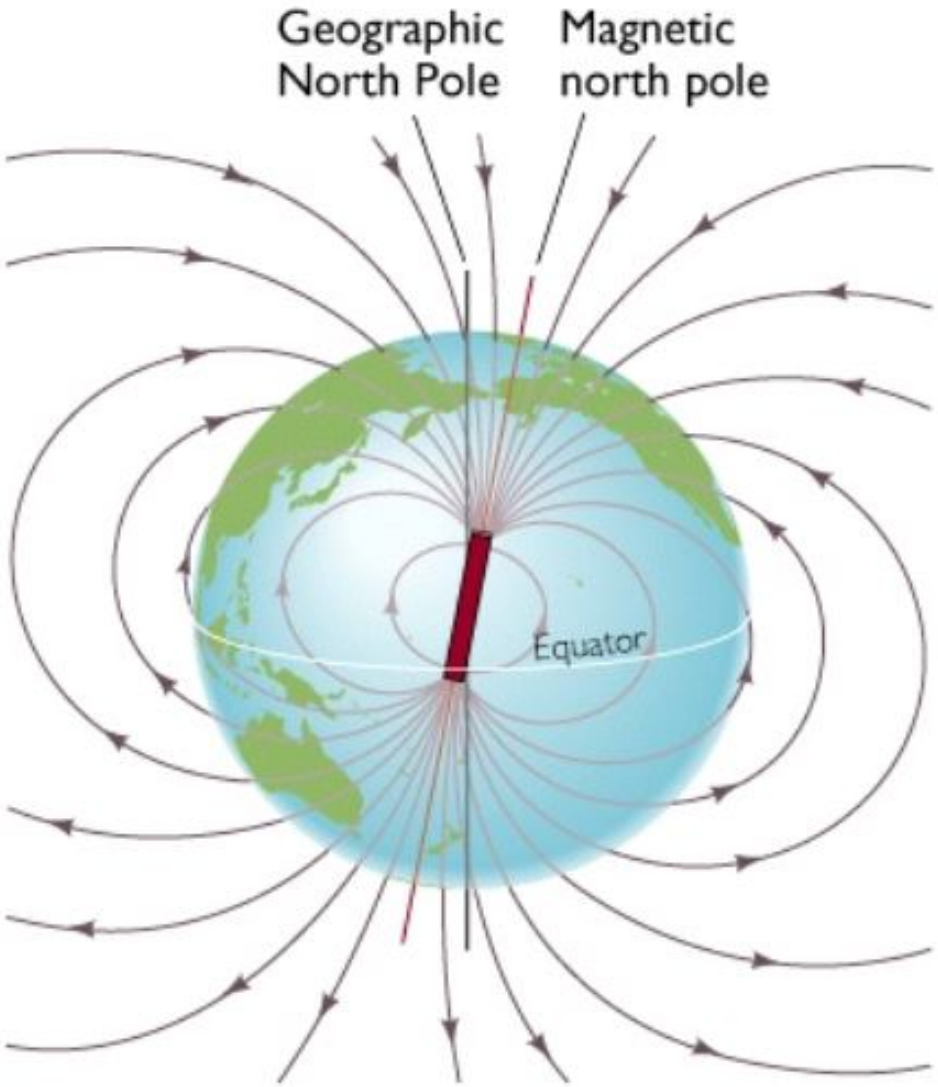


Testing the Plate Tectonics Model



Evidence: Paleomagnetism

- Magnetic field has a north pole and a south pole (think of a compass)
- Paleomagnetism: natural remnant magnetism in rocks…the permanent magnetization acquired by rock that can be used to determine the location of the magnetic poles and the latitude of the rock at the time it became magnetized

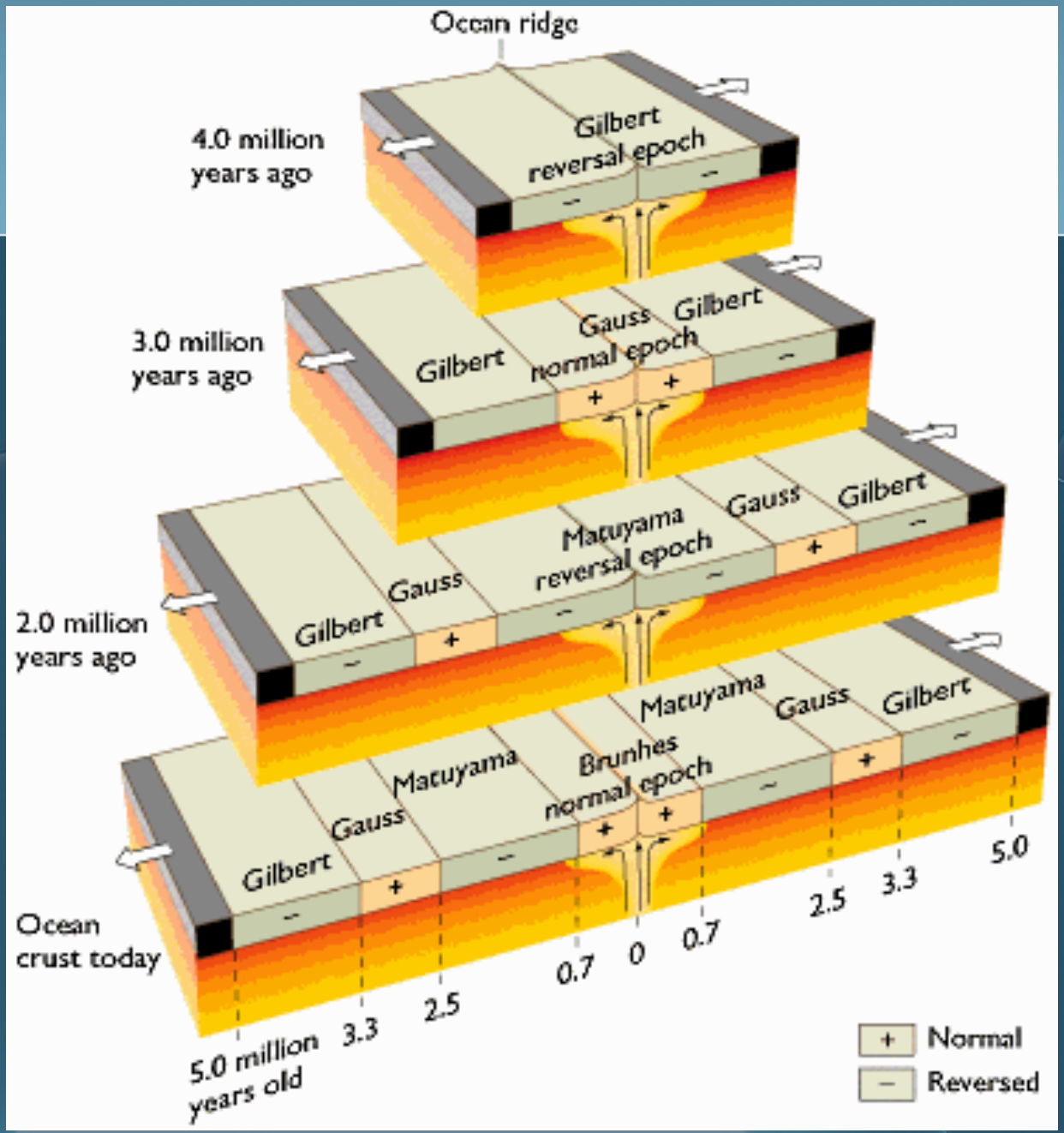


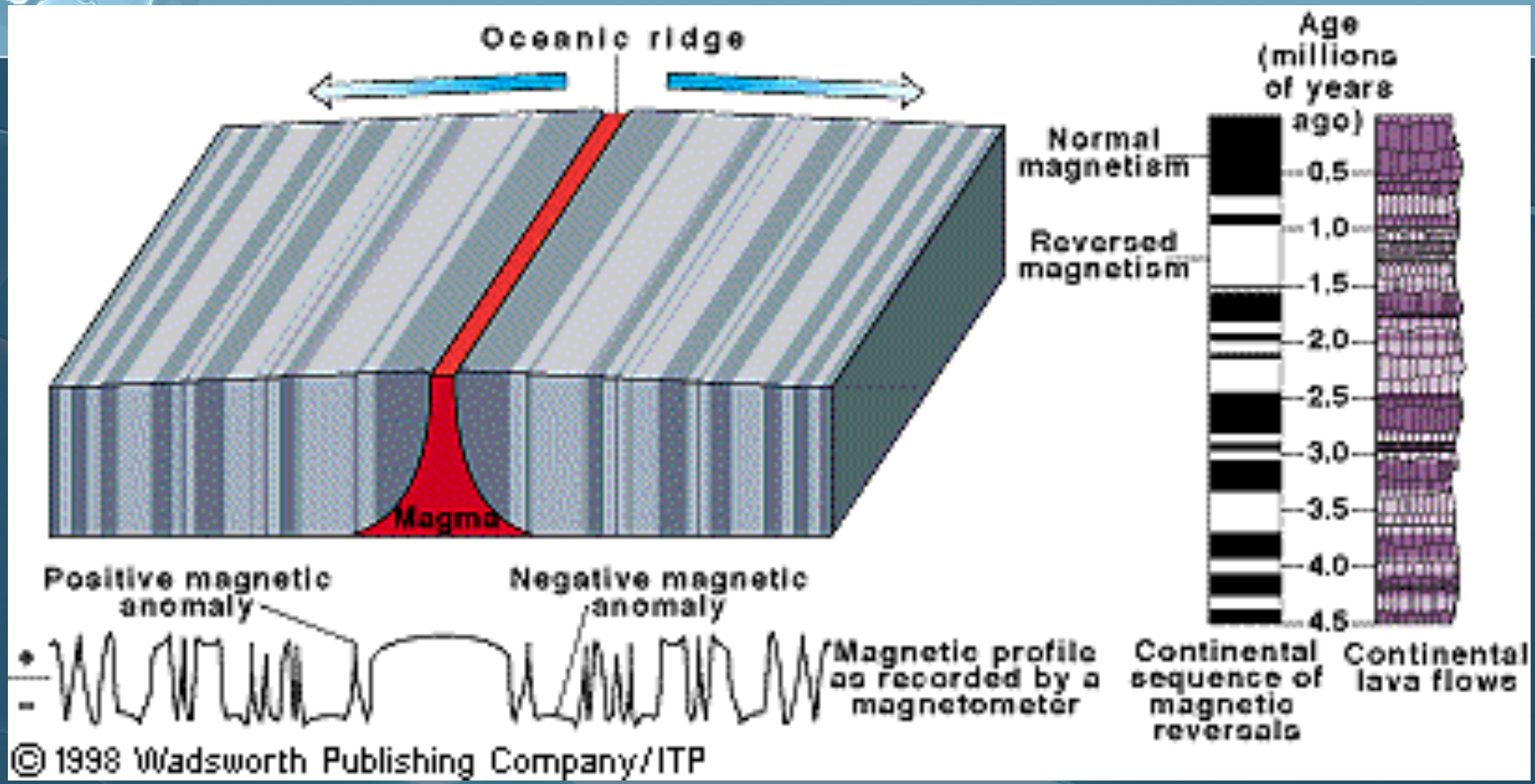
Magnetic Field of the Earth

Fig. 19.11

Paleomagnetism Continued…

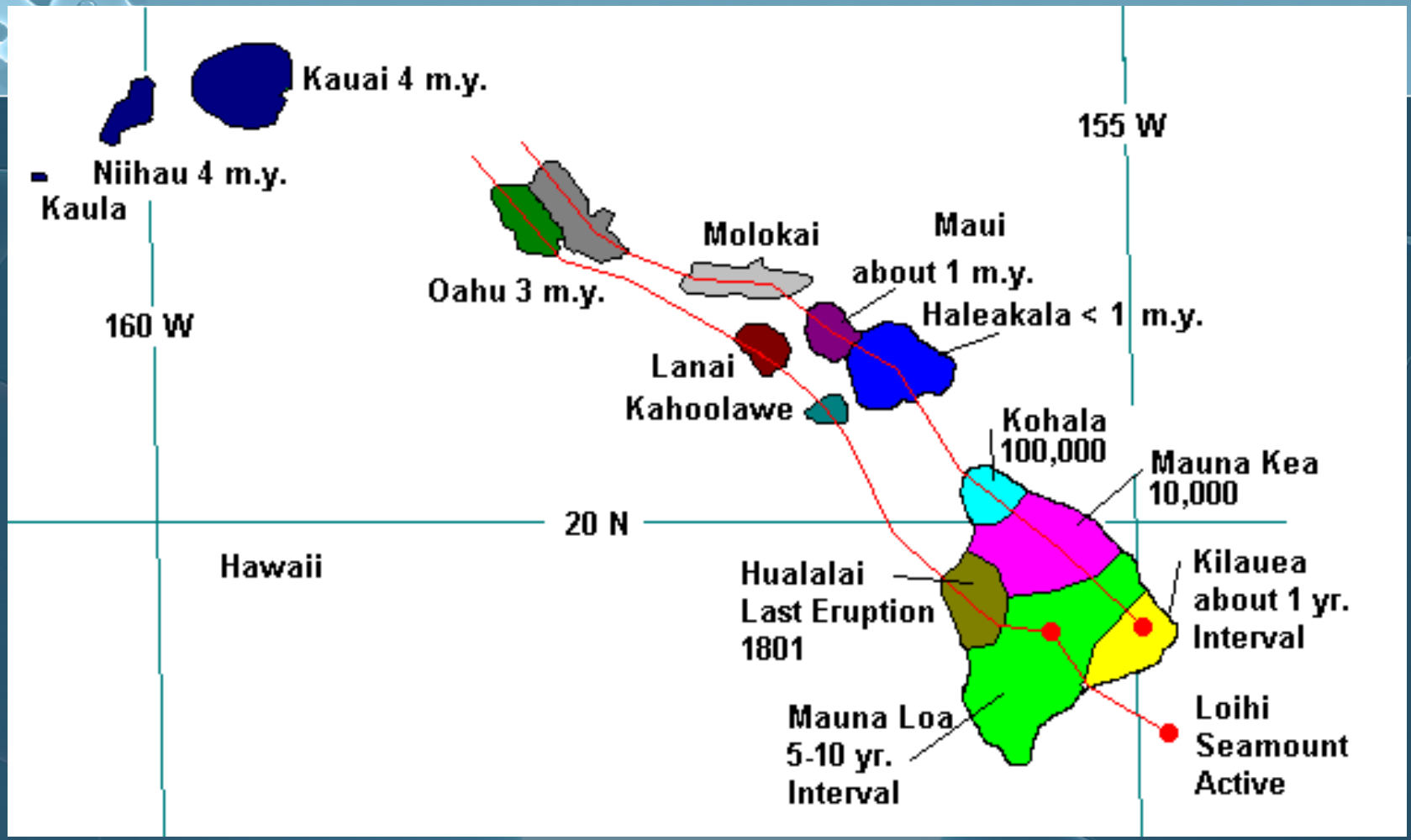
- Magnetic poles periodically reverse polarity (north pole becomes south pole and vice versa)
  - Normal polarity (same as present) vs. reverse polarity (opposite of present)
  - Tied to sea floor spreading (1963)--- alternating strips of normal and reverse polarity on both sides of the ridges
  - Pacific Ocean strips are much wider that those in the Atlantic (Pacific spreads faster)


Ocean ridge
4.0 million years ago
Gilbert reversal epoch
3.0 million years ago
Gilbert
Gauss normal epoch
Gilbert
2.0 million years ago
Gilbert
Gauss
Matuyama reversal epoch
Gauss
Gilbert
Ocean crust today
Gilbert
Gauss
Matuyama
Brunhes normal epoch
Matuyama
Gauss
Gilbert
5.0 million years old
5.0
3.3
2.5
0.7
0
0.7
2.5
3.3
5.0
Normal
Reversed


Oceanic ridge
Magma
Positive magnetic anomaly
Negative magnetic anomaly
+
-
Magnetic profile as recorded by a magnetometer
Age (millions of years ago)
Normal magnetism
Reversed magnetism
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Continental sequence of magnetic reversals
Continental lava flows
© 1998 Wadsworth Publishing Company/ITP

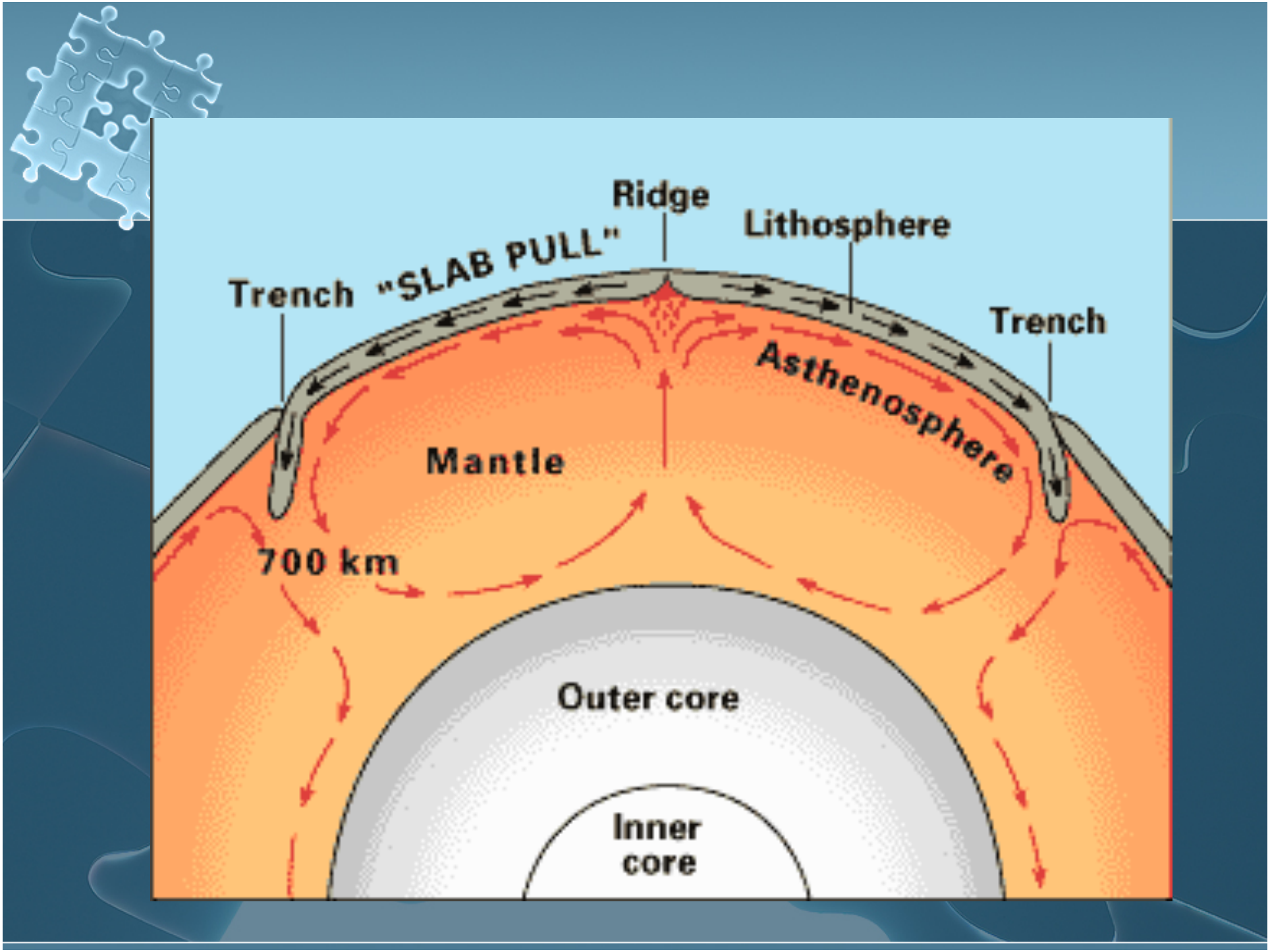
More Evidence

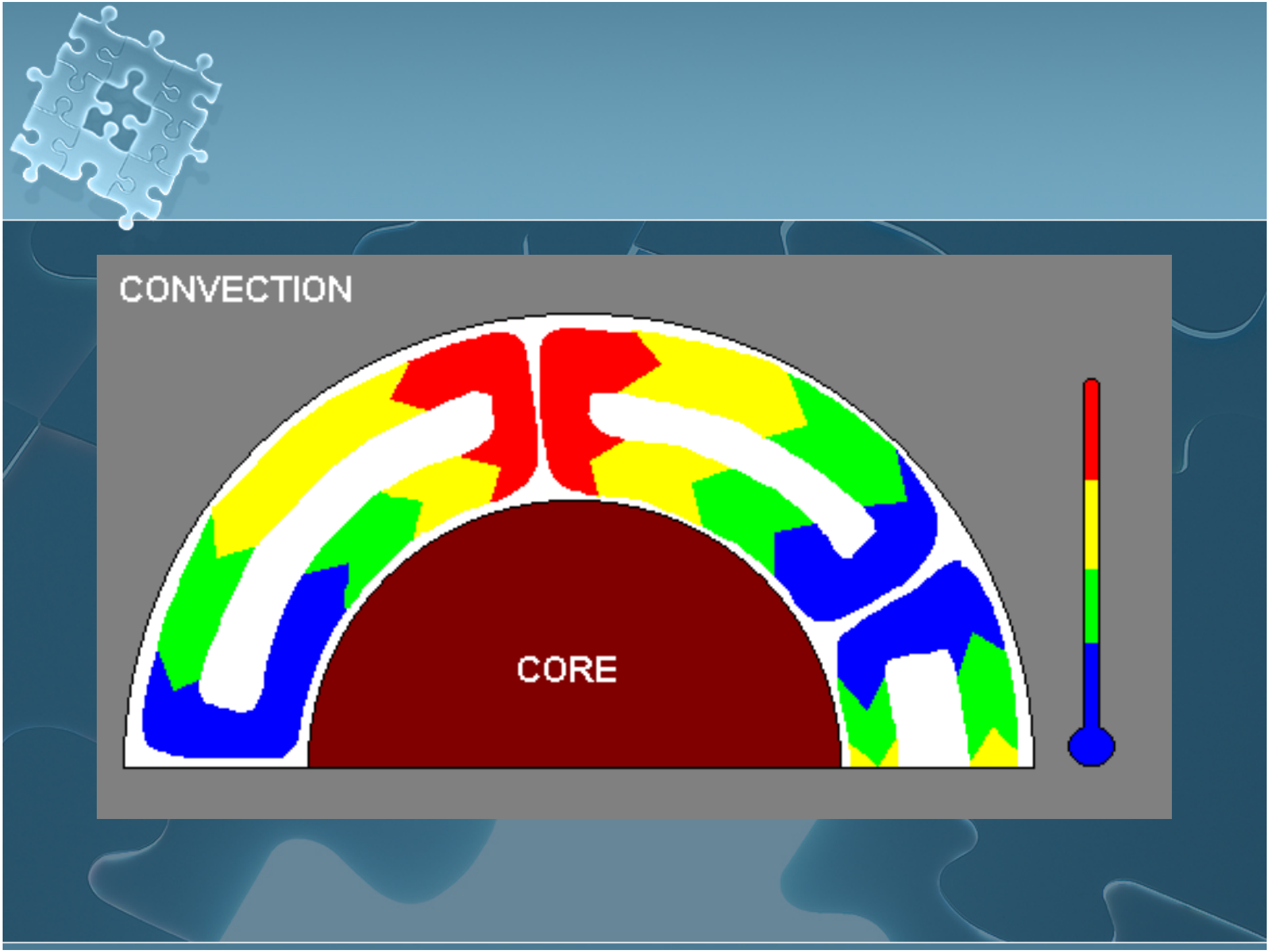
- Earthquake Patterns
  - Plate tectonics model accounts for the distribution of earthquakes
- Ocean Drilling
  - Age of sediment increased with increasing distance from the ridge
  - Oceanic crust is young when compared with continental
- Hot Spots
  - Volcanoes increase with age with increasing distance from Hawaii
  - See pg. 216


Kauai 4 m.y.
Niihau 4 m.y.
Kaula
155 W
Molokai
Maui
about 1 m.y.
Oahu 3 m.y.
Haleakala < 1 m.y.
160 W
Lanai
Kahoolawe
Kohala
100,000
Mauna Kea
10,000
20 N
Hawaii
Hualalai
Last Eruption
1801
Kilauea
about 1 yr.
Interval
Mauna Loa
5-10 yr.
Interval
Loihi
Seamount
Active

The Driving Mechanism

- Mantle Convection
  - Warm, less dense rock rises and cooler, more dense material sinks
  - Think of heating soup on a stove
  - Three models
    - See pg. 221


Ridge
Lithosphere
Trench "SLAB PULL"
Trench
Asthenosphere
Mantle
700 km
Outer core
Inner core


CONVECTION
CORE